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Biological Services Program

FWS/OBS-81/44
SEPTEMBER 1981

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FEASIBILITY OF USING GEOTHERMAL EFFLUENTS FOR WATERFOWL WETLANDS

Fish and Wildlife Service

EPA

U.S. Department of the Interior

2 0 SEP 1982

The Biological Services Program was established within the U.S. Fish and Wildlife Service to supply scientific information and methodologies on key environmental issues that impact fish and wildlife resources and their supporting ecosystems.

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United States Department of the Interior

FISH AND WILDLIFE SERVICE

OFFICE OF BIOLOGICAL SERVICES
Western Energy & Land Use Team
Drake Creekside Building
2625 Redwing Road
Fort Collins, Colorado 80526

June 22, 1982

Dear Colleague:

The U.S. Fish and Wildlife Service is pleased to announce the publication of Feasibility of Using Geothermal Effluents for Waterfowl Wetlands. A copy of the document is enclosed.

The report contains information on water quality; biology; ecology; groundwater hydrology; geology; soils; wastewater treatment; and economic, socioeconomic, and legal considerations. One of the major conclusions from the study is that, for some sites, effluents can be used for waterfowl wetlands, and there can be an associated economic benefit for developers.

Additional copies of the report can be obtained free of charge from:

Publication Manager
Information Management Services
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Western Energy and Land Use Team
2625 Redwing Road, Creekside One
Fort Collins, Colorado 80526
COM: 303/226-9300
FTS: 323-5300

Sincerely,

Carl L. Armour

Carl L. Armour
Project Officer

Enclosure

FWS/OBS-81/44
September 1981

FEASIBILITY OF USING GEOTHERMAL EFFLUENTS FOR WATERFOWL WETLANDS

by

CH_2M Hill
200 S.W. Market Street
12th Floor
Portland, Oregon 97201

Contract Number 14-16-0009-79-121

Project Officer

Carl Armour
Western Energy and Land Use Team
2625 Redwing Road
Fort Collins, Colorado 80526

Performed for
Western Energy and Land Use Team
Office of Biological Services
Fish and Wildlife Service
U.S. Department of the Interior
Washington, DC 20240

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PREFACE

This project was conducted to evaluate the feasibility of using geothermal effluents for developing and maintaining waterfowl wetlands. Information in the document pertains to a seven State area in the West where geothermal resources have development potential.

Information is included on physiochemical characteristics of geothermal effluents; known effects of constituents in the water on a wetland ecosystem and water quality criteria for maintaining a viable wetland; potential of sites for wetland development and disposal of effluent water from geothermal facilities; methods of disposal of effluents, including advantages of each method and associated costs; legal and institutional constraints which could affect geothermal wetland development; potential problems associated with depletion of geothermal resources and subsidence of wetland areas; potential interference (adverse and beneficial) of wetlands with ground water; special considerations for wetlands requirements including size, flows, and potential water usage; and final conclusions and recommendations for suitable sites for developing demonstration wetlands.

EXECUTIVE SUMMARY

The feasibility of using geothermal effluent water to develop and maintain wetlands was evaluated. Idaho, Montana, Nevada, New Mexico, northern California, Oregon, and Utah were included in the study area. Physical and chemical properties of geothermal effluent water were described for 206 sites in the seven States.

State-of-the-art criteria for properties of effluent water necessary for viable wetland ecosystems were developed. Capabilities of wetlands to treat effluents, Federal and State regulations which could hinder wetlands development with geothermal water, the potential for geothermal resources to be depleted if water is used for wetlands, possible subsidence problems at wetland sites, and the potential for ground water contamination by wetlands were analyzed.

Potentials of the 206 sites for wetlands were evaluated to the extent possible by applying the state-of-the-art water quality criteria and considering factors including availability of land for a wetland, land use suitability, topographic suitablility, ground water contamination potential, and waterfowl use potential.

Conclusions for the study were:

- Use of geothermal effluents for establishing and maintaining waterfowl wetlands seems technically and economically feasible.
- Sites with the most development potential are in the Beaverhead area of Montana (two sites), the Camas area of Idaho (two sites), and the Nye area of Nevada (five sites). The potential for all of the 206 sites could not be determined because information necessary for the evaluations was incomplete. When additional data are available, some of these sites may be determined to be potentially suitable. Numbers of potentially suitable new sites should increase as geothermal exploration continues and additional geothermal areas are discovered.
- High technology pretreatment is not economically feasible for sites with pronounced water quality problems. The subsurface injection of effluent is probably best for these sites.
- Wetlands can probably remove certain contaminants in effluent water to render water released from the wetlands suitable for irrigation use.
- General cost comparisons of subsurface injection versus wetlands disposal indicate that injection is favored for sites with high effluent flows and zero discharge requirements. If variances for the zero discharge could be obtained, wetland disposal would be economical. Site-specific analyses will be necessary to determine the benefit/cost comparisons of injection versus wetland disposal for each site considered for development.

- Legal and institutional factors affecting wetland development seem to be State-specific. Section 318 Federal Water Pollution Control Administration (FWPCA), the aquaculture section, may provide a legal way to use wetlands to process water from geothermal facilities.

- The need for injecting geothermal fluid depends on the characteristics of a geothermal reservoir. Volcanic and vapor reservoirs are least dependent on injection for replenishment.

- The potential for surface subsidence when water is not injected back to a subsurface geothermal reservoir depends on the geologic structure. Volcano-tectonic sites and all liquid geothermal reservoirs have the greatest potential for subsidence.

- Local topography, evaportranspiration, and characteristics of the zone of aeration (i.e., thickness, composition, permeability, and soil type) can alter the chemical composition of the effluent during seepage from a wetland to an aquifer.

- The characteristics of geothermal effluents and site potentials for developing and maintaining wetlands vary. All sites considered for wetland development will require site-specific studies before suitabilities can be accurately evaluated.

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INTRODUCTION

The U.S. Fish and Wildlife Service (FWS) has adopted the goal of developing methods to enhance or mitigate fish and wildlife resources in the development of new energy technologies in rapid growth areas (predominantly Western States). This position recognizes that Western energy sources will be developed and utilized and that an innovative approach to recycling of energy-related wastes must be found to achieve a positive ecosystem balance.

The U.S. Environmental Protection Agency (EPA), concerned about the potential for contamination of the environment by new energy developments, is supportive of projects (including this study) designed to study alternative methods for disposal of energy-related wastes.

Geothermal energy shows promise for alleviating some of the Western States' dependence on foreign oil. Development of the geothermal resource involves extracting high-temperature fluids or vapors from cavities (reservoirs) deep within the earth's crust. After the usable energy of the geothermal resource has been consumed (for electric generation or some direct-heat use), the effluent (in the case of fluid reservoirs) is generally injected back to the reservoir. The only electrical generating facility currently using a geothermal source is at the Geysers in California; it is a vapor-dominated system. Numerous direct-use systems are in operation; a few examples are aquaculture, home and commercial heating, and food processing.

Many geothermal resources in arid Western States have effluent water quality as good as surrounding surface waters. In these arid States, even water of marginal quality has optimum value for fish and wildlife populations because of limited existing supplies. Wetlands are dwindling in acreage across the United States and significantly in the Western States because of dredge and fill activities. Wetlands are extremely important because they offer a wide variety of habitats for wildlife, especially waterfowl. Development of wetlands in arid States could have a considerable positive impact on wildlife populations by offering resting stops, forage, and cover during migratory periods, possibly attracting permanent populations. Excess geothermal process water could potentially be used to develop habitat and thereby enhance fish and wildlife populations.

OBJECTIVES

Evaluation of the feasibility of using geothermal effluents to create waterfowl wetlands involves a multidisciplinary phased approach, in which a number of tasks are completed in a logical sequence.

Seven tasks were performed in this study, including:

1. Compilation of physical and chemical data on geothermal resource fluids that show promise for commercial development in Idaho, Montana, Nevada, New Mexico, northern California, Oregon, and Utah.

2. Determination of the ecological significance of constituents found in geothermal effluents and of what levels are safe to maintain a healthy wetlands system.

3. Classification of all sites identified into three categories (usable, questionable, and unusable), according to the criteria developed in No. 2.

4. Determination of the feasibility of using wetlands for wastewater treatment and assessment of legal or institutional and socioeconomic constraints to wetlands development.

5. Evaluation of generic and site-specific geologic features that would preclude wetlands development.

6. Evaluation of generic and site-specific potential contamination of ground water aquifers by downward migration of effluent from the wetlands.

7. Evaluation of the optimum land area and volume of geothermal effluent for a wetlands development.

GEOTHERMAL EFFLUENT CHARACTERIZATION

INTRODUCTION

The growing interest in potential utilization of geothermal energy in the western United States has led a variety of agencies, including the Department of Energy (DOE) and the U.S. Geological Survey (USGS), to systematically catalogue geothermal resource data. Because of the possible commercial development of these resources, the scope of Task 1 involved establishing criteria that would identify those geothermal areas where commercialization is most likely to occur within the next decade in New Mexico, northern California, Nevada, Utah, Oregon, Idaho, and Montana. Task 1 also included projecting the probable use of the energy in these areas and chemically and physically characterizing them so that focus could be made on the potential for wetlands enhancement or development from the wastewater resulting from their commercialization.

METHODS

Several criteria were established before the review of the available literature (DOE Hydrothermal Commercialization Baseline Studies and USGS computer file GEOTHERM) to exclude geothermal sites not likely to be developed within the next decade or sites for which insufficient data existed to permit judgments. These criteria were temperature, geographic location, and availability of chemical data.

Temperature was the most powerful screening criterion. Geothermal sources having temperatures below 64° C were excluded from the data set because of the low probability of commercial development at a source with low temperatures. Sources having temperatures between 64° and 100° C are useful for local space heating, greenhouse, or aquaculture operations. Sites with temperatures between 100° and 150° C hold good potential for such industrial uses as food and plastics processing. Geothermal sources with temperatures greater than 150° C could be used to produce electrical power.

Geothermal sources having temperatures above 150° C were considered to have the greatest potential for development within the next decade. Geographic and chemical data concerning these sites were considered of secondary importance because of the wide range of potential commercial applications at these temperatures. All sites identified in this temperature range are included in this report.

The potential for development of geothermal waters in the 100° to 150° C range depends, to some extent, on their geographic location. The possible use of their thermal energy for food or plastics processing, or for the production of low-grade steam to be used for various other industrial uses, suggests that proximity to metropolitan or agricultural centers is important. Sources in the 100° to 150° C range that are not within a reasonable distance (10 to 20 miles) from a population or agricultural center were excluded from this report. The importance of chemical data for sites in this temperature range depended greatly on the geographic location of the source. The development of sites close to populated or agricultural areas is considered probable. Consequently, sites located in desirable areas were not necessarily excluded from this report if chemical data were lacking.

The screening process for geothermal sources in the 64° to 100° C range put great emphasis on both the geographic location and the availability of chemical data. Sources in this temperature range were considered to have the least potential for development because of the relatively few applications considered feasible for the thermal energy they possess. Sites not located near a metropolitan area and sites having no available chemical data were excluded from this report.

For several sites, geothermal sources were identified that met none of the established criteria but had been developed previously or were in the development process. These sites are not included in this report.

RESULTS

Within the seven target States, 206 individual geothermal sites from 60 different geographic areas were identified as locations where commercial development could occur within the next 10 years (Figure 1). Overall, nine sites were identified as having electrical generation potential, 22 as having industrial application potential, and 175 as having space heating capabilities. The principal chemical constituents of all the sites identified include sodium, sulfate, carbonate, chloride, and silica. Geothermal sources located in the same geographic area tended to have the same principal chemical constituents, although the concentrations of these primary chemicals are not necessarily similar. The presence or absence of trace elements and heavy metals, and their concentrations, varied widely among sites within any given geographic area.

Table 1 presents the principal chemical constituents, temperature ranges, and probable energy uses for each State. Site-specific chemical and physical data for each State are presented in Appendix A, Tables A-1 through A-7 (DOE Hydrothermal Commercialization Baseline Studies, USGS computer file GEOTHERM).

Idaho

Fourteen areas with potential for commercial development were identified. These areas are distributed across the southern part of the state, most of them having only one site. The Raft River (Cassia Co.) and Boise (Ada Co.) areas show the most potential and the greatest number of proposed and ongoing programs. Among the others, only the Weiser Crane Creek area showed potential for possible industrial applications; all the other sites were suitable only for space heating applications.

Crane Creek, Weiser, and Big Creek are being considered for possible industrial applications; Bruneau, Sun Valley Ketchum, Boise, Raft River, Twin Falls, and Malad are either using or considering geothermal space heating projects.

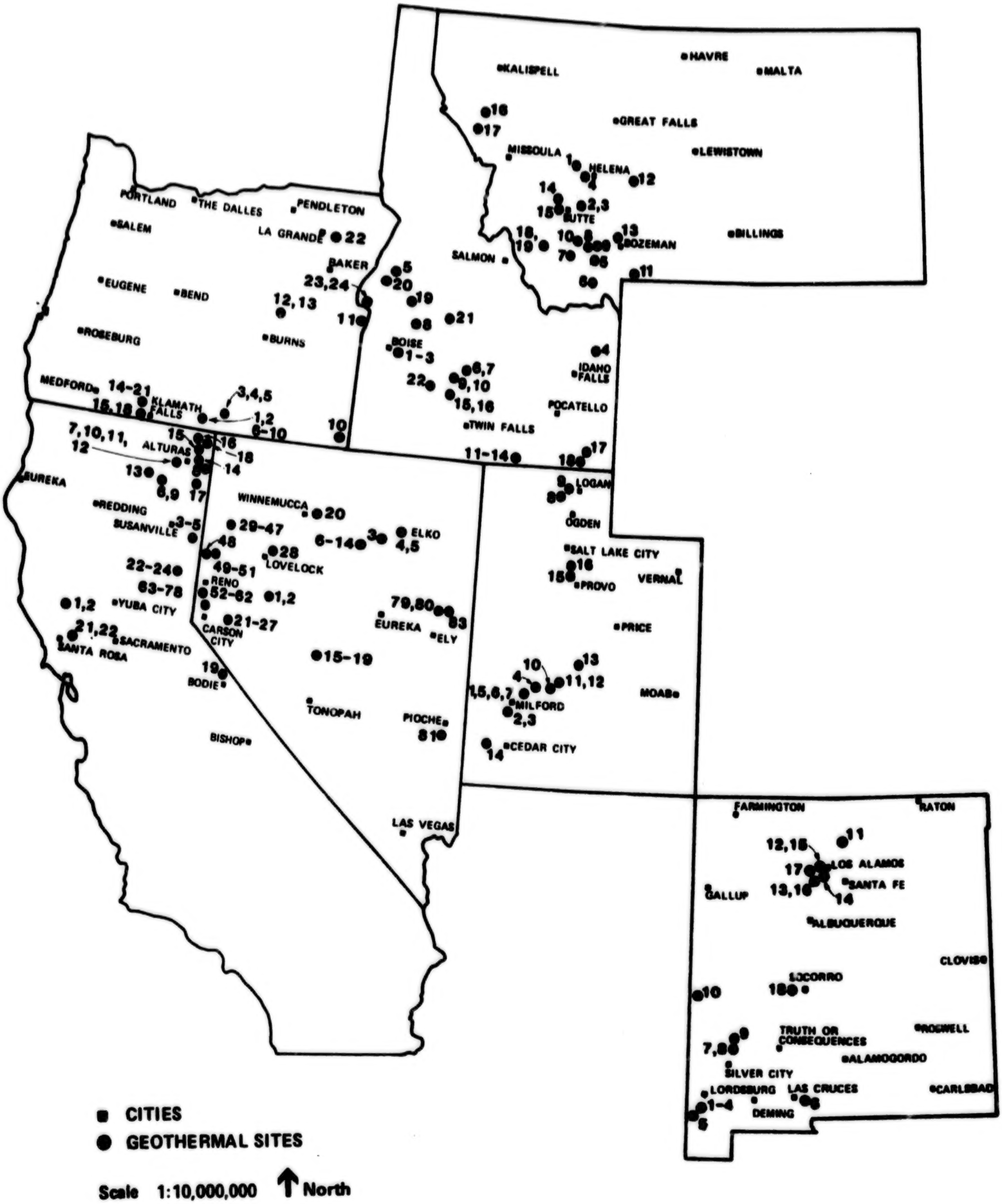

Figure 1. Location of initial geothermal sites in the seven State project area.

Table 1. Features of Geothermal Sites

State	Area Designation	Resource Name	Site Numbers	Principal Chemical Constituents	Temperature Range (°C)	Probable Energy Uses
Idaho	Ada	Boise	1,2,3	Na,HCO_3, SiO_2	75-80	Space heat
	Madison	Boise	4	Na,HCO_3, SiO_2	75-80	Space heat
	Adams 1	Cascade Reservoir	5	Na, SO_4, SiO_2	65	Space heat
	Blaine	Sun Valley/ Ketchum	6	Na, SO_4, SiO_2	70-81	Space heat
	Blaine	Sun Valley/ Ketchum	7	Na, SO_4,SiO_2	70-81	Space heat
	Boise	Grimes	8	Na, HCO_3, SiO_2	80	Space heat
	Camas	Coral	9,10	Na,HCO_3	66-70	Space heat
	Cassia	Raft River	11,12,13,14	Na,Cl	96-147	Space heat Industrial
	Elmore	Glenns Ferry/ Bliss	15	Na,HCO_3,SiO_2	65-68	Space heat
		Pine	22	No chemistry	74	Space heat
	Gooding	Glenns Ferry/ Bliss	16	Na,HCO_3,SiO_2	65-68	Space heat
	Franklin	Liberty	17	Na,Cl	76	Space heat
		Glendale	18	Na,K,Cl,HCO_3	77	Space heat
	Valley	Cascade	19	Na	70	Space heat
	Custer	Sunbeam	21	Na,HCO_3,SiO_2	76	Space heat
	Adams 2	Mesa	20	Na,SO_4,Cl	76	Space heat
	Washington	Weiser/Crane Creek	23,24	No chemistry	?	Space heat
Montana	Lewis and Clark	Helena	1,4	Na,HCO_3,SO_4	57-97	Space heat
	Jefferson	Helena	2,3	Na,HCO_3,SO_4	57-97	Space heat
	Madison	Ennis/Sheridan	5,6,7,8,9,10	Na,HCO_3,SO_4,Ca	50-83	Space heat
	Park	Bozeman	11	Na,HCO_3,SO_4,Ca	46-55	Space heat
	Meagher	Bozeman	12	Na,HCO_3,SO_4,Ca	46-55	Space heat
	Gallatin	Bozeman	13	Na,HCO_3,SO_4,Ca	46-55	Space heat
	Deer Lodge	Anaconda/ Walkerville	14,15	Na,SO_4,Ca	70-77	Space heat
	Sanders	Flathead Indian Reservation	16,17	Na,HCO_3	43-45	Space heat
	Beaverhead	Dillon	18,19	Na,HCO_3	49-58	Space heat
Nevada	Churchill	Stillwater	1,2	Na,Cl	96-100	Space heat
	Elko	Carlin	3	HCO_3	79	Space heat

Table 1. (continued)

State	Area Designation	Resource Name	Site Numbers	Principal Chemical Constituents	Temperature Range (°C)	Probable Energy Uses
Nevada (continued)	Elko	Elko	4,5	No chemistry	64-100	Space heat
	Eureka	Beowawe	6-14	Na,SiO_2	77-100	Space heat
	Nye	Darrough's	15-19	Na,SiO_2	88-100	Space heat
	Humbolt	Golconda	20	HCO_3	74	Space heat
	Lyon	Wabuska	21-27	Na,SO_4	94-108	Space heat Industrial
	Pershing	Colado	28	Na,Cl	66	Space heat
	Washoe 1	Gerlach	29-47	Na,Cl	63-100	Space heat Industrial
	Washoe 2	Pyramid	48	Na,Cl	82	Space heat
	Washoe 3	Pyramid	49-51	Na,Cl	66-67	Space heat
	Washoe 4	Moana	52-62	Na,SO_4	64-93	Space heat
	Washoe 5	Steamboat Springs	63-78	Na,Cl	66-161	Space heat Electrical generation
	White Pine 1	Warm Springs	79,80	HCO_3	79	Space heat
	White Pine 2	Cherry Creek	83	-	152	Electrical generation
	Lincoln	Caliente	81	SiO_2,HCO_3	67	Space heat
	Esmerada	-	82	-	158	Electrical generation
New Mexico	Hidalgo 1	Lightning Dock	1,2,3,4	Na,SO_4,HCO_3	75-102	Space heat Industrial
	Hidalgo 2	Lightning Dock	5	Na,SO_4,HCO_3	99	Industrial
	Dona Ana	Los Alturas	6	Na,HCO_3,Cl	25-45	Space heat
	Grant 1	Gila	7	Na,HCO_3	52	Space heat
	Grant 2	Gila	8	Na,HCO_3	64	Space heat
	Catron 1	Gila	9	Na,HCO_3	65	Space heat
	Catron 2	San Francisco Hot Springs	10	Na,SO_4,$CaHCO_3$	37	Space heat
	Taos	Los Alamos/Taos	11	Na,SO_4,$CaHCO_3$	37-45	Space heat
	Sandoval 1	Los Alamos/Taos	12,15	Na,SO_4,$CaHCO_3$	49-285	Space heat Electrical generation
	Sandoval 2	Los Alamos/Taos	13,16	Na,SO_4,$CaHCO_3$	66-76	Space heat
	Sandoval 3	Los Alamos/Taos	17	Na,SO_4,$CaHCO_3$	197	Electrical generation
	Socorro	Socorro	18	Na,HCO_3	33	Space heat

Table 1. (continued)

State	Area Designation	Resource Name	Site Numbers	Principal Chemical Constituents	Tempera-ture Range (°C)	Probable Energy Uses
Northern California	Lake	-	1,2	Na,SO_4,HCO_3,Cl	99-186	Electrical generation
	Lassen 1	Honey Lake Valley	3	Na,SO_4,Cl	95	Space heat Industrial
	Lassen 2	Honey Lake Valley	4	Na,SO_4,Cl	107	Industrial
	Lassen 3	Honey Lake Valley	5	Na,SO_4,Cl	96	Industrial
	Modoc 2,3, 5-10	Surprise Valley/ Modoc Plateau	7,8,10-18	Na,SO_4,Cl	79-160	Space heat Industrial Electrical generation
	Lassen 4		6			
	Lassen 5		9			
	Mono	-	19	Na,SO_4,HCO_3,Cl	69	Space heat
	Napa 1	-	20	Na,SiO_2,Cl	98	Space heat Industrial
	Napa 2	-	21	Na,SiO_2,Cl	137	Industrial
	Sierra	Sierra Valley	24			
	Plumas 1-3	Sierra Valley	22,23	Na,SO_4,Cl	70-94	Space heat
Oregon	Lake 1	Lakeview	1,2,6,7,8,9	Na,SO_4,Cl	69-96	Space heat
	Lake 2	Lakeview	3,4	Na,SO_4,Cl	78,99	Space heat
	Lake 3	Lakeview	5	Na,SO_4,Cl	68	Space heat
	Malheur 1	-	10	Na,SO_4,Cl	88	Space heat
	Malheur 2	Vale	11	Na,SO_4,SiO_2,Cl	73	Space heat
	Harney	Fields	12,13	Na,SO_4,Cl	73-79	Space heat Industrial
	Klamath 1	Klamath Falls	14,16,17,19, 20,21	Na,SO_4	71-89	Space heat
	Klamath 2	Klamath Falls	15,18	Na,SO_4	90-93	Space heat
	Union	La Grande	22	SiO_2	?	Space heat Industrial
Utah	Beaver 1	Milford	1	Na,SiO_2,Cl	85	Space heat
	Beaver 2	Milford	2,3	Na,SiO_2,Cl	77-85	Space heat
	Millard	Milford	4	Na,SiO_2,Cl	77	Space heat
	Beaver 3	Milford	5,6,7	Na,SiO_2,Cl	133-260	Space heat Industrial Electrical generation
	Box Elder 1	Brigham City	8	Na,Cl	74	Space heat
	Box Elder 2	Brigham City	9	Na,Cl	105	Industrial

Table 1. (concluded)

State	Area Designation	Resource Name	Site Numbers	Principal Chemical Constituents	Temperature Range (°C)	Probable Energy Uses
Utah (continued)	Sevier 1	Joseph	10	Na,SO_4,Cl	64	Space heat
	Sevier 2	Monroe	11,12	Na,SO_4,Cl	75-77	Space heat
	Sevier 3	Vermillion	13	No chemistry	66	Space heat
	Iron	Escalante Desert	14	No chemistry	149	Industrial
	Salt Lake 1	Salt Lake City	15	No chemistry	?	Space heat
	Salt Lake 2	Salt Lake City	16	No chemistry	?	Space heat

Montana

The 19 geothermal sources are in the 64° to 100° C temperature range, suitable mainly for space heating applications for residences and possibly greenhouses. Most of the sites identified are currently involved in direct use projects.

The thermal applications all involve space heating ventures. The largest are the Warm Springs State Hospital (Deer Lodge Co.); a nursing home (Jefferson Co.); and a school, community center, baths, and swimming pool (Sanders Co.).

Nevada

Nevada has perhaps the greatest potential for commercial development; 83 sites were identified. Applications for geothermal energy utilization range from space heating to electrical generating possibilities. Areas showing great potential for development are the Moana (Reno) and Steamboat Springs regions in Washoe County.

Proposed use of geothermal energy involves space heating plans in Caliente and the heating of a 6,000-dwelling development in the Moana (Reno) area. Crescent Valley (Eureka Co.) has an alcohol distillery-feedlot facility planned, and Caliente (Lincoln Co.) has proposed a geothermal source to attract industry. Phillips Petroleum is exploring the potential for power development at its Desert Peak site.

New Mexico

New Mexico has 18 geothermal sites: two sites show good potential for electrical generation. The area with the greatest potential for development is near Los Alamos, in the Valley Caldera, Sandoval County. A 50-MW demonstration plant, built by Union Oil and the Public Service Company of New Mexico, is to be in operation in 1982 at this location.

The use of geothermal energy in New Mexico is currently limited to space heating projects, the largest of which involves heating a 10 story building in Albuquerque (Bernalillo Co.) with the aid of a heat pump.

Northern California (North of 38.00°N Latitude)

Six geographic areas containing 24 geothermal sites were identified. Potential commercial opportunities range from space heating to electrical production. Most of the sites are located in the Surprise Valley-Modoc Plateau area of Modoc County.

Projects in Northern California that have been proposed and/or initiated include: a space heating and food processing venture for a hog farm in Modoc County; residential and greenhouse heating, a wood chip drying project, and a boiler water preheating project for an electrical plant near Susanville; space heating in a lumber store and a feasibility study concerning the use of geothermal energy to heat the Mammoth Lake ski resort in Mono County; a proposal to heat homes and greenhouses and to initiate an aquacultural program on the Fort Bidwell Indian Reservation; and a feasibility study concerning the use of geothermal energy to process tungsten ore in Bishop (Mono Co.).

Oregon

Five areas having good potential for geothermal development were identified, including two areas (Klamath Falls and Lakeview) where the relatively extensive use of geothermal energy is currently underway.

A variety of direct uses and proposals for geothermal energy uses exist in Oregon, including: residential and greenhouse heating, aquaculture (prawn production), milk pasteurization, concrete curing, and experimental highway de-icing near Klamath Falls (Klamath Co.); aquaculture (trout farm), residential and greenhouse heating in the Lakeview area (Lake Co.); experimental alcohol distilling and greenhouse heating (Boise-Cascade seedlings) near LaGrande (Union Co.); and a slaughterhouse and greenhouse heating venture in Vale (Malheur Co.).

Utah

Among the 16 geothermal sources in Utah, three of the areas identified had no chemical data available. Most of the geothermal energy development is occurring in the Milford area (Beaver Co.).

The potential for development in Utah ranges from space heating to electrical generation. Projects and proposals involving heat for pools, residences, greenhouses, and hog farms exist in Monroe, Salt Lake City, New Castle, Honeyville, Belmont, and Burrow. A pilot project concerning an alcohol distillery using geothermal energy is underway near Cove Fort, and an electrical generation plant is planned near Milford.

ECOLOGICAL CRITERIA DEVELOPMENT

INTRODUCTION

This section discusses the known physical and chemical effects of constituents in geothermal effluents on biological groups required for the successful functioning of a wetlands ecosystem. It also establishes constituent-specific criteria for geothermal effluents to be used in wetlands to support various floral and faunal components.

In order to develop ecological criteria for a healthy wetlands system, the literature was examined to determine the biological and ecological attributes of a healthy marsh. Next, the various chemical and other constituents of geothermal effluents were examined to determine their effects on the biological components of wetlands. Thermal considerations and flow requirements are briefly discussed in relation to the overall biological wetlands system. State water quality requirements are also described, as well as the ability of wetlands to treat the effluent to meet the requirements. Table 4 indicates maximum concentrations of individual constituents in geothermal effluent recommended for use in a wetlands ecosystem. Two levels of acceptability designated Level 1 and Level 2, were established for effluent use in wetlands.

METHODS

Several data sources were used to compile the background information presented in this section. These include:

- DOE Hydrothermal Effluent Commercialization Baseline Studies.
- USGS computer file GEOTHERM.
- Computer searches and literature review concerning data on waterfowl food and habitat requirements and interactions of geothermal chemical constituents with wetlands flora and fauna.
- Contacts with Federal, State, and industrial wildlife biologists concerning waterfowl management techniques and problems.
- Contacts with water quality control agencies in each of the States in the study area.

BACKGROUND INFORMATION

Wetlands Ecosystems

Wetlands, especially marshes, are typically structured as concentric zones of vegetation at various degrees of inundation, often surrounding an open water area. These zones are delineated by different vegetative life forms that are adapted to life in water or in soils that are at least periodically saturated (Cowardin et al. 1977).

The species composition of wetlands varies depending on fluctuation in temperature, water depth, pH, turbidity, salinity, nutrient availability, and season. Synergistic reactions between factors add to the complexity of community interactions. For example, a 2° C increase in temperature in conjunction with a pH change can initiate a change from a green algae dominated community to one in which bluegreen algae dominate (McKee and Wolfe 1963).

Algal communities are the dominant vegetative life form in deeper water (>2 m). As water depth decreases, submergent and floating-leafed vegetation becomes more abundant. These types of vegetation obtain nutrients primarily from the soil, but they also have the capacity to absorb nutrients directly through the stomata of the leaf. Sago pondweed and duckweed, both important waterfowl food items, are examples of these vegetative life forms. Other species common to this group include chara, plantain, smartweed, and widgeon grass. Many of these species are important as habitat for invertebrates, rather than as direct food items for waterfowl. Table 2 lists the common and scientific names of predominant marsh species.

Emergent vegetation, dependent solely on soil for nutrients, can be divided into deep marsh, shallow marsh, and wet meadow life-form zones. Deep marsh zones are closest to the open water edge, consisting of tall, robust cattails and/or bulrush. These offer cover and their rhizomes serve as minimal food items for many species of waterfowl. Shallow marsh zones offer grasses and grass-like plants, including mannagrass, sedge, spikerush, and arrowgrass. The wet meadow zone is the least likely to be permanently inundated. A variety of species can occur, depending on length of inundation, soil type, elevation, and other factors. Saltgrass, sudan grass, wild rice, reed, rush, and wild millet are common in freshwater marshes (Sloan 1970). Saltwater areas are dominated by pickelweed, cordgrass, sea-blite, and saltgrass.

This type of zonation is produced mainly by varying water levels and results in horizontal plant diversity, an attractive habitat for waterfowl. The particular species of vegetation are secondary in importance, compared with the structure of the marsh for waterfowl usage (Weller 1978).

Wetlands are dynamic habitats and, consequently, are extremely productive. Yearly production values average 4,000 g/m²/yr (Whittaker 1975), one of the highest rates relative to other ecosystems (Odum 1971). Water depth and frequency and duration of inundation are all factors that affect wetlands production (de la Cruz 1978).

The chemical composition of soils also helps determine species composition and productivity. This, too, is affected by water depth and by frequency and duration of inundation. As the chemical nature of soils changes, the chemical content of the associated vegetation is altered (Stefferud 1957; Richardson 1978). The extent of alteration within the vegetation that is tolerable depends on: (1) initial chemical concentration within the plant tissue; and (2) the effects of synergistic and antagonistic reactions of the physical environment on the plant.

Animal matter is an important seasonal food supplement for many species of waterfowl. During the nesting and brooding seasons, laying hens and young ducklings require a diet higher in protein than can be supplied by vegetation alone. Benthic invertebrates and aquatic insects can provide a large portion

Table 2. Plant species list of important wetland and forage species.

Scientific name	Common name
Emergent Species	
Carex spp.	Sedge
Distichlis spicata	Saltgrass
Echinochloa crusgalli	Barnyard grass (wild millet)
Eleocharis aricularis	Spike rush
Equisetum fluviatile	Water horsetail
Iris sp.	Iris
Juncus spp.	Rush
Phalaris lemmonii	Canary grass
Phragmites communis	Reed
Phleum sp.	Swamp timothy
Sagittaria spp.	Arrowhead
Salicornia pacifica	Pickleweed
Scirpus spp.	Bulrush
Sorghum sudanense	Sudan grass
Spartina spp.	Cordgrass
Sueda californica	Sea-blite
Triglochin maritima	Arrow grass
Typha spp.	Cattail
Zizania aquatica	Wild rice
Zizaniopsis miliacea	Water millet
Submergent Species	
Alisma sp.	Water plaintain
Altemanthera philoxeroides	Alligator weed
Ceratophyllum demersum	Hornwort
Chara sp.	Muskgrass (algae)
Eichhornia crassipes	Water hyacinth
Elodea sp.	Water weed
Lemna minor	Duckweed
Myriophyllum sp.	Water milfoil
Plantago sp.	Goose tongue
Ploygonum spp.	Smartweed
Pontederia	Pickerelweed
Potamogeton pectinatus	Sago pondweed
Potamogeton spp.	Pondweed
Polycarpaea sp.	Pink
Ruppia maritima	Widgeon grass
Zannichellia palustris	Horned pondweed
Zostera marina	Eelgrass

Table 2. (concluded)

Scientific name	Common name
Various Algal Species	
Chlorella sp.	
Cirosiphon sp.	
Scenedesmus sp.	
Vaucheria sp.	
Forage Species[a]	
Astragalus sp.	Locoweed
Atriplex sp.	Saltbush
Avena sp.	Oats
Bromus sp.	Brome
Dactylis glomerata	Orchard grass
Fescue sp.	Fescue
Glycine max	Soybean
Hordeum vulgare	Barley
Lolium sp.	Rye
Medicago sativa	Alfalfa
Sorghum vulgare	Sorghum
Triticum sp.	Wheat
Zea mays	Corn

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[a] Forage species are those species (either naturally occurring or specifically planted in upland areas of wetlands or marshes) that are utilized by wildlife as a food source. Many species appearing on the list are cultivated as part of management programs at wildlife refuges throughout the seven subject States. These species are included in this report because the possibility exists that geothermal waters will be used to irrigate forage crops for waterfowl as part of the cascading uses of effluent waters.

of that protein. Driver et al. (1974) studied invertebrate food species in Utah and Manitoba. They found that chironomids were the main component in the diet of flightless dabbling ducks and mallards. Hemiptera and molluscs were the prime food items of blue wing teal, and amphipods were the prime food of lesser scaup. Although these invertebrate species were important during that study, waterfowl are predominantly opportunistic feeders and could be expected to use any available food source. Other animal food items include Trichoptera larvae, decapods (crayfish), Coleoptera, small fish, leeches, and oligochaetes. Shovelers are even known to use zooplankton, such as cladocerans, in their diet.

Chemical Constituents of Effluent

The flora and fauna that will be able to utilize spent geothermal fluids will be determined mainly by the temperature and chemical composition of the waters. Some geothermal waters are more capable of supporting desirable aquatic life than others. Waters with high total dissolved solids (TDS) and large quantities of toxic elements (such as mercury, cadmium, arsenic, and hydrogen sulfide) will probably not be able to support a productive waterfowl ecosystem.

One of the primary goals of this study was to develop a set of ecological criteria to determine the feasibility of establishing wetlands in conjunction with geothermal developments. Determination of the tolerances of important marsh species to the chemical constituents identified in Section 3 is an important part of developing these criteria.

Tables 3 and 4 summarize chemical parameters in relation to their effects on the principal biological groups constituting wetlands communities. A range of concentrations that produce toxic effects for each constituent is presented. Appendix B presents the supporting information for these tables. The parameters listed are those for which data were found, both from geothermal resources listed in Task 1 and from the literature on tolerance limits for one or more principal biological groups. Thirty-six chemical parameters are listed.

The toxicity levels given in Tables 3 and 4 show a wide degree of variance, which is caused by several factors. One of the more important is the fact that chemical analyses of geothermal sources typically report on elemental or radical values. The actual compounds present, an important aspect of assessing toxicity levels, are generally unknown. Thus, the wide toxicity ranges indicated for some of the elements are at least partially a result of including a number of compounds under the same heading. Probably equally important are the wide range of test conditions, response criteria, and different species used in assessing toxicity ranges for major biological groupings (e.g., "aquatic invertebrates").

Flora. Approximately 70% of the chemical constituents identified would not be expected to pose severe toxicity problems to vegetation when found at the levels present in most geothermal sources. Reported toxicity tolerance ranges of several species include levels higher than those found in the geothermal sources studied. In instances where bioaccumulation occurs, toxic effects generally do not occur in the concentrating species. Rather, effects are more liable to occur at higher trophic levels.

Table 3. Summary of effects of geothermal constituents on flora.[a]

Constituent	Geothermal Range (ppm)	Toxicity Range (ppm)	Bioaccumulation	Comments
Aluminum (Al)	0-2	1-20	No	No data available on effects on marsh species.
Arsenic (As)	0-2.7	0.1-10 .1 irrigation of crops[b]	No	Tolerance limits of several aquatic plants in the 4-5 ppm range. Exhibits antagonisms with Zn, Fe, and Al compounds.
Barium (Ba)	.00001-.2	>10	No	Waterweed killed at 10 ppm soluble Ba. Most plants only exhibit toxic effects under extreme conditions.
Beryllium (Be)	.005-.007	0.1-2	No	No data for marsh plants. Usually unavailable in soils.
Boron (B)	0-828	0.8-2 .75 for sensitive crops[b]	No	Raft River effluent did not harm crop species. Several aquatic species accumulated B with no toxic effects.
Cadmium (Cd)	<.002-.1	.005-.1	Yes	Marsh plants readily take up, translocate, and accumulate Cd.
Calcium (Ca)	.28-320	-[c]	No	Essential macronutrient. No apparent direct toxic effects at levels tested.
Chromium (Cr)	<.02-<.04	5-20 .1 freshwater aquatic life[b]	No	Accumulated by roots of marsh plants, but not translocated.
Copper (Cu)	.004-.08	.2-10	No	Submerged aquatic plants unaffected at 10 ppm Cu.
Fluorides (F)	0-24	-	Variable	No apparent toxicities from aqueous uptake. Gaseous and particulate fluorides may concentrate sufficiently to pose bioaccumulation problems.
Iron (Fe)	0-76	-	No	Extremely abundant element. Adverse effects related to deficiencies.
Lead (Pb)	.003-.07	5-20	Yes	Usually unavailable in soils. 10 ppm results in greatly decreased production in aquatic plants.
Magnesium (Mg)	0-73	>25	No	Essential to plant growth. Often found at high levels in plant tissues with no toxic effects.

Table 3. (concluded)

Constituent	Geothermal Range (ppm)	Toxicity Range (ppm)	Bioaccumulation	Comments
Manganese (Mn)	0-15	2-20	Yes	Often concentrated to high levels by aquatic plants with no toxic effects.
Mercury (Hg)	.00007-.02	-	Yes	Methylated form most toxic, but rarely found in soils.
Molybdenum (Mb)	Trace	-	Yes	Toxicity not a problem to plants, but can poison animals if excessive amounts (>5 ppm) occur in forage.
Nickel (Ni)	<.02-.08	-	No	Normally toxic at "low levels."
Phosphate (PO_4)	.01-1.4	-	No	An essential nutrient. Aquatic plants can absorb high concentrations. Problems mainly related to eutrophication of standing waters.
Potassium (K)	.15-660	-	No	An essential element. Commonly accumulated to high levels by aquatic vegetation with no toxic effects.
Selenium (Se)	0-.014	5-300	Yes	Toxicity level applies to non-accumulating plants. Duckweed and many other plants can accumulate high Se levels. Livestock poisoning occurs at >5 ppm.
Sodium (Na)	5.8-3,100	Variable	No	Cattail and bulrush relatively tolerant.
Zinc (Zn)	.005-2.32	<10 ppm	No	An essential micronutrient. Deficiencies more common than toxicities. Readily accumulated and translocated by marsh plants.

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[a] See Appendix B.
[b] EPA recommended criterion.
[c] Undetermined.

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Table 4. Summary of effects of goethermal constituents on fauna.[a]

Constituent	Geothermal range (ppm)	Avian toxicity range (ppm)	Aquatic invertebrate toxicity range (ppm)	Aquatic vertebrate toxicity range (ppm)	Bioaccumulation	Comments
Aluminum (Al)	0-2	-[b]	6.7	.07-133	No	Little information available.
Antimony (Sb)	.005-.4	-	9-37	9-20	-	Rapidly precipitates into sediments. Probably not a problem.
Arsenic (As)	0-2.7	-	1.1-20	5-60	No	Food chain transference has low toxicity due to organic binding.
Ammonia (NH3)	<.01-4	-	90-134	0.6-24.7	No	Unionized form is by far the more toxic.
Barium (Ba)	.00001-.2	-	11.1-170	200-4,400	No	Sulfates and carbonates relatively insoluble. Most toxicity studies conducted on chlorides and nitrates.
Beryllium (Be)	.005-.007	-	-	0.15-20.3	No	Normally present in only trace amounts. Few data available.
Boron (B)	0-828	-	5.2-240	1,600-19,000	No	Generally low toxicity.
Bromine (Br)	0-3	-	10	20	Yes	Apparently bioaccumulates, but no toxicity data associated with this phenomenon.
Cadmium (Cd)	<.002-.1	20-200	0.005-4.9 .004-.012[c]	0.017-80	Yes	Exhibits synergisms with other metals as well as direct toxicity at very low concentrations. Toxic effects in waterfowl related to kidneys, testes, and egg production and are sublethal.
Calcium (Ca)	.28-320	-	920-1,730	160-56,000	No	Unlikely to present problems.
Cesium (Cs)	.001-4.76	-	-	-	Yes (radioactive forms)	Radioactive forms bioaccumulate, but the element and its salts react similarly to potassium and are not considered toxic.
Chromium (Cr)	<.02-<.04	-	.016-148 .1[c]	2-300	No	Fish generally more tolerant than invertebrates.

Table 4. (continued)

Constituent	Geothermal range (ppm)	Avian toxicity range (ppm)	Aquatic invertebrate toxicity range (ppm)	Aquatic vertebrate toxicity range (ppm)	Bioaccumulation	Comments
Copper (Cu)	0.004-008	-	0.0024-32 0.1 x 96 hr LC_{50}^{c}	0.009-1.25	No	Extremely toxic constituent in reactive state exhibiting numerous synergisms and antagonisms. Relatively nontoxic in combined state with any degree of water hardness.
Chloride (Cl)	0.5-5,400	-	variable	2,000-10,500	No	The chloride ion readily complexes with many elements, leading to extremely variable toxicity values. Tolerances of even fresh water species are relatively high.
Fluorides (F)	0-24	-	270	419	variable	Not considered a problem in aqueous state. Deposition of particulates a potential problem.
Hydrogen Sulfide (H_2S)	0-7.4	-	0.059-1.07 0.002 undissociated H_2S^{c}	0.002	No	A very toxic component which concentrates under anaerobic conditions.
Iodine (I)	0.01-.24	-	-	28.5	-	Unlikely to present problems
Iron (Fe)	0-76	-	0.32 0.001^{c}	0.9	No	Generally not a problem in aerated waters due to oxidation and precipitation.
Lead (Pb)	0.003-.07	<200 mg. (ingested metal)	0.3-64 .01 x 96 hr LC_{50}^{c}	.4-75	Yes	Not considered a direct problem, but bioaccumulation possible.
Lithium (Li)	0.01-20	-	2.6	2.6	-	The 2.6 value is for "aquatic organisms." Li is a rare element and few data are available.
Magnesium (Mg)	0-73	-	400-3,500	100-400	No	Not considered a problem.
Manganese (Mn)	0-1.5	-	5.7-700 $.1^{c}$	15-40	Yes	Not considered a direct problem, but could bioaccumulate.
Mercury (Hg)	0.00007-0.02	.1-.5	0.006-2.1 0.00005^{c}	0.0001-.?	Yes	Toxic at low levels. Poses bioaccumulation problems and exhibits synergisms.
Nickel (Ni)	<0.02-0.08	-	0.51-64 0.01 x 96 hr LC_{50}^{c}	4.58-9.82	No	Moderately toxic to fresh water organisms.

Table 4. (concluded)

Constituent	Geothermal range (ppm)	Avian toxicity range (ppm)	Aquatic invertebrate toxicity range (ppm)	Aquatic vertebrate toxicity range (ppm)	Bioaccumulation	Comments
Nitrates (NO_3)	0-42		2670	420	No	Not considered a problem except for eutrophication potential.
Nitrites (NO_2)	0-.12	-	-	1.5	No	Not generally considered a problem in natural surface waters.
Potassium (K)	.15-660	-	127-1,000	50-2,010	No	Most common form (KCl) is least toxic.
Selenium (Se)	0-.014	-	2.5 .01 x 96 hr LC_{50}[c]	2.9-40	Yes	Carcinogenic and teratogenic.
Silver (Ag)	.004-.02	-	.0051-.15 .01 x 96 hr LC_{50}[c]	.003-.0043	-	Nitrates and sulfates most toxic forms to aquatic life.
Sodium (Na)	5.8-3,100	-	1,000-2,100	1,000-2,000	No	Increasing concentrations alter community structure.
Sulfates (SO_4)	2-4,520	-	0.01-7105	12-34,000	No	Moderately toxic within range of geothermal sources.
Tin (Sn)	<.02-<.2	-	25-146	-	No	Not considered a problem.
Vanadium (Vn)	-	25-300	-	-	No	Some evidence of effects on lipid metabolism and interaction with calcium mobilization.
Zinc (Zn)	.005-2.32		.1-.3 .1 x 96 hr LC_{50}[c]	.88-.96	No	Relatively toxic when reactive; nontoxic when combined. Exhibits synergisms with copper and nickel. Will be in combined state with any amount of hardness present in geothermal effluent.

[a] See Appendix B.
[b] Undetermined.
[c] EPA recommended criterion.

Fauna. It is obvious from Table 4 that toxic levels for aquatic biota are best known, and direct toxicities to waterfowl are least known. Approximately one-half the listed constituents either occur at levels that could directly affect aquatic fauna or are known to be bioaccumulated. In general, aquatic invertebrates are sensitive to chemicals in their environment. Chemical constituent levels in excess of listed minimum toxicity levels do not preclude the existence of more hardy species capable of existing in many geothermal waters. As an example, when a natural environment is proposed to be altered, toxicity levels are often assessed for the most sensitive organisms present in an attempt to ensure viability of the entire ecosystem. Cladocerans (Daphnia spp.) have been found to be among the most sensitive organisms (Kenaga and Moolenaur 1979) and are often used in establishing toxicity levels. However, their presence in a wetlands is not essential for productive waterfowl habitat.

Other Constituents

Along with the chemical constituents discussed above, several other parameters of geothermal waters are worthy of special note, including temperature, flow, pH, total dissolved solids (TDS), organic sulfur compounds, chlorinated hydrocarbons, radionuclides, and atmospheric emissions. Ranges for these parameters in the geothermal sources identified in Section 3 are:

Temperature	64 - 161° C
Flow	<1 - 17,034 gpm
pH	2.0 - 9.9
TDS	119 - 85,000 ppm
Radionuclides	0.2 µµC/l (reported in one well)
Atmospheric emissions	None reported in well data

Temperature and flow are discussed in later sections.

pH. The U.S. Environmental Protection Agency (1976) has established a recommended pH range of 6.5-9.0 for protection of freshwater life, based on bioassays using fish and aquatic insects. Values outside the recommended range may be directly toxic or may adversely shift the solubility of toxic chemical constituents, affecting potential toxicity.

TDS. In general, the hotter the geothermal resource, the higher the TDS concentrations, and the greater the potential for environmental degradation. Although TDS data are available for most areas, the value of this measurement is limited because of the lack of specific information about the discrete elements included. McKee and Wolf (1963) state that the limiting concentration of TDS for freshwater species is unknown but lies approximately between 5,000 and 10,000 ppm for most species. They also state that there could be an antagonistic relationship between TDS and heavy metals.

Radionuclides. Radionuclides are present in trace amounts in virtually all geothermal wells. The eventual concentration of radionuclides that could accumulate in the soil depends on a number of factors, such as initial concentration (in picocuries per liter), rate of application, and rate of radioactive decay (U.S. Environmental Protection Agency 1974). The level of radionuclides in geothermal waters is well below that which would cause damage in plants.

The potential problem lies with the extent to which a plant will concentrate radionuclides and the potential bioaccumulation through the food chain (McKee and Wolf 1963).

Plants can absorb radionuclides directly into foliage or through the roots from contaminated soils (U.S. Environmental Protection Agency 1972).

Exceedingly high levels of radioactivity can cause somatic damage to vegetation and can possibly have a genetic effect.

Although some plant species can strongly concentrate radionuclides, most plants do not concentrate them to the extent that damage occurs.

Crops grown at the Hanford Nuclear Plant and irrigated with 5% reactor fluid showed no increase in beta activity (an indicator of radioactivity) over control crops. This indicates an apparent lack of concentration from low-level radionuclides contamination. There is, however, a general lack of experimental evidence concerning long-term accumulation of low levels of radionuclides.

Atmospheric Pollutants. Geothermal wells produce very little in the way of atmospheric pollutants. At the Geysers in California, a dry-steam well, only 1% of the steam is composed of noncondensable gases. This is considerably less than the concentrations of noncondensable gases produced by fossil fuel plants of similar size. At the Geysers, 80% of the noncondensable gas is CO_2, with various small percentages of CH_4, H_2, HN_4, and H_2S. H_2S is the most serious pollutant, averaging 4.5% of the gases and 225 ppm of the steam (U.S. Fish and Wildlife Service 1976).

In an attempt to determine toxicity levels of H_2S, sensitive plant species were exposed to 40 ppm H_2S. These species were slightly injured at this concentration. Other more tolerant species failed to show injury after exposure to 400 ppm H_2S (Jacobsen and Hill 1969).

Effects of H_2S are highly variable because of specific site conditions, such as sensitivity of vegetation present, atmospheric conditions, wind patterns, topography, and numerous other factors. The absence of literature on H_2S injury to plants indicates the relative unimportance of this gas (Jacobsen and Hill 1970).

The most prevalent noncondensable gas emitted at the Geysers is CO_2 (U.S. Fish and Wildlife Service 1976). This has no known harmful effects on vegetation and can be beneficial, because it has a stimulatory effect on photosynthesis.

Thermal Considerations

Temperature ranges of geothermal waters under consideration are between 64° and 161° C. The geothermal effluent discharge temperature from a process may vary widely depending on the system's efficiency, use rate, type of control, and utilization. Even within similar industrial or commercial applications, discharge temperatures will vary.

Recognizing this tendency toward variation, generalized discharge temperature can be typified as 100° C from power plants, 55° C from most industrial applications, and 30° C from agricultural uses. In some applications the spent geothermal fluids can be successively utilized by lower temperature processes (cascaded), thereby lowering the discharge temperature available to a wetlands.

Waters for propagation of higher aquatic vegetation typical of wetlands communities must be at a maximum temperature of 40° C (Salisbury and Ross 1969). Similarly, photosynthetic ability of algae is generally irreversibly damaged above 41° C, although some bluegreen algae are tolerant of up to 80° C (Patrick 1974).

Below 40° C, increased temperature can have both desirable and deleterious effects on plant growth. Temperature is a principal controlling factor governing growth, through its effect on metabolic rate. Increased water temperatures hasten and extend the growing season for added productivity. Thermal marshes also have a statistically greater decomposition rate than ambient temperature marshes. This enables bound nutrients to be more rapidly available for reuse within the mineral cycle. Increased water temperatures thus enable marshes to maximize the energy flow through the system and carry on metabolism at increased levels (Young 1974).

Increased metabolism does not, however, always produce beneficial results. Root respiration rates increase with increasing temperatures, raising oxygen consumption logarithmically. Because the dissolved oxygen concentration of water is inversely related to temperature, oxygen availability is lowered as temperature and respiration rate increase, causing physiological stress. Symptoms of this water stress have been noted to occur at temperatures only 6° C above ambient (Miller 1974). Cordgrass experiences dwarfing of stem size in thermal marshes, probably as a result of this phenomenon. Algal communities are also greatly influenced by temperature. Small temperature increases at the lower end of the tolerance range increase diversity and biomass of the algal community. Elevated temperatures enhance competition, eventually bringing about a shift in species composition (Patrick 1974; Saks et al. 1974).

Most warmwater animal species are unable to maintain populations in waters much hotter than 30° C (McKee and Wolf 1963; U.S. Environmental Protection Agency 1976). Those waters having temperatures ranging between 30° and 75° C do, however, support a limited number of invertebrate groups. Among those groups adapted to this temperature range are adult bean shrimp (Cypris balnearea) and a mite (Thermacarus) that can tolerate waters up to 52° C. Faunal groups capable of living in waters up to 40° C include Nematoda, Oligochaeta, Ostracoda, some Malacostraca, Odonata, Dytiscidae, Hydrophilidae, Ephydridae, Stratiomyidae, Chironomidae, and some gastropods [e.g., Limnaea, Melanopsis, and Paludistrina (Hynes 1970)]. Carp (Cyprinus carpio) and mosquitofish (Gambusia affinis) are also tolerant of waters up to approximately 40° C.

In addition to speeding up metabolic rates, elevated temperatures coagulate cell protein, break down certain enzymes, and possibly change makeup of body fats. They have an added negative effect on aquatic fauna in that the amount of dissolved oxygen is decreased, making respiration difficult for most organisms (Miller 1977). The sensitivity of fish to toxicants and diseases increases at higher temperatures because of this decrease in oxygen concentration. More water must be passed over the gills for respiration; therefore, more toxic materials pass over these permeable membranes. Many chemicals are more reactive in elevated temperatures, thereby increasing the total dissolved solids as well as potential for occurrence of toxic trace elements.

Although numerous studies of waterfowl habitat associations have been conducted, few have dealt with temperature as a habitat parameter. In a study of heated and unheated portions of a nuclear plant cooling reservoir in South Carolina, Brisbin (1974) showed that various species of waterfowl respond quite differently to water temperatures. In winter (when most ducks were present), temperature differences between areas were as great as 10° to 15° C. Unheated portions in the winter averaged about 15° C and the heated portions 30° C. Significantly more ducks and greater species diversity were recorded in the unheated portions of the reservoir. Dabbling ducks seemed more sensitive to temperature than diving ducks. However, among diving ducks, lesser scaup and bufflehead were more temperature-tolerant than other species such as ring-necked ducks and ruddy ducks. Coots showed a preference for unheated areas, while pied-billed grebes were either indifferent or in some months preferred the heated area. The preferences shown by waterfowl in this study may be related to food availability rather than direct response to temperature. Changes in food may be directly related to temperature sensitivities. No temperature limits for waterfowl were determined by this study, although an avoidance of water at 30° C and above has been recorded (Brisbin 1974).

Flow Requirements

The amount and seasonal flow of wastewater from geothermal developments will also help determine the feasibility of creating wetlands for waterfowl. Since wetlands and waterfowl populations are dynamic, management of water resources will be required to maintain and maximize their value.

The volume of effluent is obviously the prime factor in determining the ultimate size of the wetlands it will maintain. In studies conducted in Utah it was estimated that 1 cubic foot per second (cfs; approximately 450 gallons per minute) would develop about 100 acres of wetlands (Jensen 1974). A great many variables affect the volumes needed, such as evaporation rate and soil permeability. Thus, 1 cfs per 100 acres should be viewed as a minimum water requirement.

The seasonality of water flow is another feature of proper wetlands management. Periodic drying of wetlands is necessary to release important nutrients, such as phosphates, that become bound in bottom material. Exposure to air oxidizes the nutrients, making them available when inundated again. Some valuable wetlands plant species also require occasional drying to maximize seed production. However, these management techniques may also present dangers to waterfowl. Botulism (western duck disease) may develop, killing large numbers of waterfowl when certain conditions are present (Hunter et al. 1970; Bellrose 1978). Slowly receding water can strand and kill many aquatic invertebrates that provide an anaerobic medium for botulism-producing bacteria (Clostridium botulinum Type C) to grow. Waterfowl feeding on these invertebrates consume toxin produced by the bacteria, become sick, and often die. Further, maggots feeding on waterfowl carcasses can be consumed by other waterfowl, infecting them. Methods to prevent this in problem areas include:

design for rapid draining and inundation; develop steep-sided wetlands with minimum shoreline; provide deep water; avoid receding waters in summer and fall; and scatter waterfowl in affected areas. Unfortunately, these are often contradictory to methods that would otherwise maximize wetlands development. Obviously, the potential disease problem must be evaluated for each site.

State Water Quality Standards

The effluents resulting from the commercialization of geothermal sites, due to their physical and chemical properties, represent potential sources of pollution for both surface and ground water systems. The concentrations of chemical constituents in some geothermal resources render them unsuitable for any disposal other than injection. However, other geothermal liquids appear to be of adequate quality to be used in marsh enhancement or development. One of the major considerations in marsh enhancement is that the effluents should not endanger the quality of the State's waters at any time. Some wetlands effluents, therefore, must either be disposed of in such a manner that they will not enter the surface or ground water or must be treated so they meet the State's water quality criteria. Wetlands themselves, however, have the potential to remove many pollutants from geothermal effluents, thereby reducing the potential degree of treatment needed.

Each State is committed to the protection of the water systems under its jurisdiction. Along with the Federal criteria for safe drinking water (Safe Drinking Water Act, PL 93-523), each State has established water quality criteria (Table 5) for surface waters, major drainage basins (Oregon, Nevada, New Mexico, Idaho), or for different classifications and designated uses of aquatic systems (i.e., coldwater fisheries, estuaries, and others) (California, Montana, Utah). These criteria take into consideration the status, present use, and future possibilities for particular aquatic systems. A discharge permit must be secured in every State. Effluent treatment and disposal methods are predominantly considered for each situation. The positive and negative environmental, social, and economic aspects of each proposed discharge are taken into account before the State's water regulatory body rules on an application.

Land disposal options such as irrigation, aquaculture, and impoundment are open to consideration in each of the States. Idaho, Oregon, and Nevada currently have geothermal projects that use spent fluids for beneficial uses. The two main aquaculture and irrigation projects are the DOE project in Raft River, Idaho, and the Oregon Institute of Technology project in Klamath Falls, Oregon. These projects are still in the experimental phases; however, conditional provisions have been made in these States to allow land application of geothermal effluents.

The approval or denial of a discharge request depends primarily on whether the effluent will endanger the quality of surface or ground water resources. Irrigation and impoundment require extensive studies of the local geology to determine the composition and permeability of the soils in the area. The establishment of test wells to monitor the water quality of ground water resources in the area is also required in land disposal projects. Thermal pollution is related primarily to surface water (stream and lake) discharge

Table 5. State water quality requirements.

State	Temp.[a]	TDS (ppm)	pH	Ag ppm	Al ppm	As ppm	B ppm	Ba ppm	Cd ppm	Cl ppm	Cn ppm	Co ppm	Cr ppm	Cu ppm	F ppm	Fe ppm	H_2S ppm	Hg ppm	Mn ppm	Mo ppm	Ni ppm	NO_3 ppm	Pb ppm	Se ppm	SO_4 ppm	U ppm	Zn ppm
OREGON																											
KLAMATH BASIN	+0.5°F		7.0-9.0			0.01	0.50	1.0	0.003		0.005		0.02	0.005	1.0	0.10	b		0.05				0.05				0.01
GRAND RONDE	+0.5°F	200-750	6.5-8.5			0.01	0.50	1.0	0.003		0.005		0.02	0.005	1.0	0.10			0.05				0.05				0.01
GOOSE & SUMMER LAKE	+0.5°F		7.0-9.0			0.01	0.50	1.0	0.003		0.005		0.02	0.005	1.0	0.10			0.05				0.05				0.01
MALHEUR LAKE	+0.5°F		7.0-9.0			0.01	0.50	1.0	0.003		0.005		0.02	0.005	1.0	0.10			0.05				0.05				0.01
MALHEUR LAKE	+0.5°F	750	7.0-9.0			0.01	0.50	1.0	0.003		0.005		0.02	0.005	1.0	0.10			0.05				0.05				0.01
DRINKING WATER		1,000				0.05		1.0	0.010	250			0.05	1.000	2.0	0.30			0.05			10	0.05		250		5.00
NEW MEXICO[c]		1,000	6.0-9.0	0.050	5.00	0.10	0.75	1.0	0.010	250	0.200	0.05	0.05	1.000	1.6	1.00		0.002	0.02	1.0	0.20	10	0.05	0.05	600	5.00	10.00
NEVADA[d]	9-32°C	1,000				0.05	1.00	1.0	0.010		0.010		0.05			0.30		0.002	0.05			10	0.05	0.01	250		5.00
MONTANA[e]																											
A–CLOSED	f		f																								
A–OPEN–D_1	+0.5-1.0°F		6.5-8.5																								
B–D_1	+0.5-1.0°F		6.5-8.5																								
B–D_2	+0.5-1.0°F		6.5-9.0																								
B–D_3	+3.0°F		6.5-9.0																								
C–D_1	+0.5-1.0°F		6.5-8.5																								
C–D_2	+0.5-1.0°F		6.5-9.0																								
E–F			6.5-9.5																								
GENERAL						0.02			0.010					0.180		2.20		0.001					0.10				1.00
N. CALIFORNIA																											
COLD WATERS	f																										
WARM WATERS	5°F*																										
COASTAL WATERS	20°F*			0.004		0.08			0.030		0.050		0.02	0.050				0.001			0.20		0.08				0.20
ESTUARIES	4°F*																										
ENCLOSED BAYS	20°F*																										
GENERAL		500	6.5-9.0	0.050		0.05	0.50	1.0	0.010				0.05	1.000	2.4		b	0.002				10	0.05	0.01	250		5.00
UTAH																											
DOMESTIC WATER			6.5-9.0	0.050		0.05		1.0	0.010				0.05		2.4			0.002				10	0.05	0.01			
WILDLIFE WATER	2° and 4°C[g]		6.5-9.0	0.01					0.0004		0.005		0.10	0.01		1.00	0.002	0.00005					0.05	0.05			0.05
AGRICULTURAL		1,200	6.5-9.0			0.10	0.75		0.010				0.10	0.20									0.10	0.05			
IDAHO																											
COLD WATER	22°C		6.5-9.0																								
WARM WATER	33°C		6.5-9.0																								
DOMESTIC WATER				0.05		0.05		1.0	0.010		0.200		0.05		1.4-2.4			0.002				10	0.05	0.01			

[a] These data designate either an allowable overall increase (+), an allowable ambient temperature range, or the maximum temperature allowed for the effluent above that of the receiving water (*).

[b] Levels may not be objectionable.

[c] These data represent statewide water quality criteria. Varying criteria exist for different reaches of N.M. waterways.

[d] Nevada has separate river basin water quality criteria that are not presently available. These data represent statewide drinking water criteria.

[e] Classifications A and B are for drinking waters with differing levels of treatment required. C and D water uses are for recreation and wildlife, and E and F water uses are for agriculture and industry.

[f] No change above ambient levels allowed in waters with this designation.

[g] These are the maximum increases allowed for cold and warm water systems, respectively.

proposals, not to possible land disposal techniques. Problems relating to the thermal properties of the effluents appear to be minimal, compared with chemically related issues.

Wetlands Treatment of Geothermal Constituents

The potential for using wetlands to process waste has attracted the attention of scientists and engineers worldwide. Numerous pilot programs are currently being conducted, with encouraging results (Richardson 1976 et al.; Small 1976; Tourbier and Pierson, Jr. 1976; Kadlec et al. 1977; Sutherland 1977; Williams and Works 1977; CH2M HILL 1979).

Wetlands appear to be generally tolerant of pollutant inputs. Vegetation found in wetlands has the capacity to remove suspended solids, nutrients, heavy metals, chlorinated hydrocarbons, and pesticides (Seidel 1976). The capacity to remove chemical constituents is of primary interest when dealing with geothermal effluents because wetlands could potentially serve as a treatment facility for geothermal wastewaters in order to meet State water quality standards.

Numerous investigators have studied the growth efficiency of plants in contaminated waters. Results indicate that wetlands species demonstrate high production rates and have a positive effect on the polluted waters (D'Itri 1977; Boyd 1978). Seidel (1976) demonstrated the ability of wetlands plants to eliminate or reduce toxic substances from water (Table 6) without experiencing toxic effects. Water hyacinths, for example, possess impressive capacity for purification, with high metabolic rates and high tolerance limits (Seidel 1976; Wolverton et al. 1976). Bulrush can also absorb high concentrations of contaminants without detrimental effect (deJong 1976). Reeds are particularly efficient at removing contaminants and lessening pathogenic bacteria problems (Seidel 1976).

Primary factors that control the degree of purification include percolation rate, holding capacity, duration, depth and fluctuation of water, and the area available for use (Small 1976). Considerations of elevation and latitude, soil type, and the quality of water input are important in determining area requirements. A direct relationship exists between elevation or latitude and the size of the wetlands for effective treatment (i.e., the higher the elevation or latitude, the larger the area required for effective treatment by wetlands (D'Itri 1977).

Constancy of flow rates into the wetlands for the life of the geothermal project is important. Controlled loading into the wetlands is essential, because the degree of purification is dependent on retention time (deJong 1976; Small 1976; Williams and Works 1977; Whitlow and Harris 1979).

With careful management practice and monitoring techniques, wetlands could provide suitable treatment for many geothermal wastewaters. Pretreatment, including precipitation of some of the more toxic metals, or dilution of elements in high concentrations, could prove to be necessary in certain situations.

Table 6. Absorption of chemicals by various macrophytes. (K. Seidel 1976).[a]

Species	Cu		Co		Zn		Ni		Mo		Mn		B	
	mg/kg	mg/m^2	mg/kg	mg/m^2	mg/kg	mg/m^2	mg/kg	mg/m^2	mg/kg	mg/m^2	mg/kg	mg/m^2	mg/kg	mg/m^2
Scirpus lacustris	4.8	16.13	5.63	2.28	50	168.00	1.71	5.75	0.55	1.85	1200	4032.00	14.6	49.6
Carex stricta	5.6	15.23	6.72	1.96	63	171.36	2.46	6.69	0.29	0.79	970	2638.4	21.4	58.21
Iris pseudacorus	5.7	14.14	1.11	2.75	50	124.0	1.75	4.34	0.33	0.93	382	947.36	10.3	25.41
Typha angustifolia	4.7	6.77	0.44	0.63	43	62.92	1.86	2.68	0.30	0.43	779	1121.76	24.5	35.28
Glyceria aquatica	5.6	11.65	0.48	0.99	73	151.84	1.99	4.14	0.24	0.49	586	1218.88	15.0	31.20
Phragmites communis	4.2	18.82	0.62	2.78	37	165.76	1.53	6.85	0.26	1.16	166	743.68	8.2	36.74
Acorus calamus	4.1	6.56	0.53	0.85	38	60.8	1.08	1.73	0.30	8.48	383	612.8	56.9	91.04
Sparganium erectum	5.6	7.17	1.07	1.37	76	97.28	2.27	2.91	0.24	0.31	604	773.12	40.2	51.46
Myosotis palustris	12.2	3.90	1.44	0.46	104	33.28	3.19	1.02	0.53	0.17	2000	640.0	30.8	9.86
Mentha aquatica	8.5	14.28	0.54	0.91	78	131.04	2.03	3.41	0.47	0.79	381	640.1	38.3	64.34

Species	Ca		Mg		P		K		Na		Fe		Si	
	g/kg	g/m^2	g/kg	g/m^2	g/kg	g/m^2	g/kg	g/m^2	g/kg	g/m^2	g/kg	g/m^2	g/kg	g/m^2
Scirpus lacustris	3.95	12.17	0.98	3.29	2.00	6.72	10.30	34.61	6.30	21.17	0.78	2.62	12.60	43.34
Garex stricta	4.84	13.16	2.06	5.60	2.20	5.93	13.90	38.31	2.20	5.58	3.80	10.34	17.60	47.87
Iris pseudacorus	16.97	42.09	2.58	6.39	2.50	6.20	35.40	87.79	1.70	4.22	1.30	3.22	4.30	10.46
Typha angustifolia	14.36	22.48	1.49	2.29	2.20	3.17	14.10	20.30	12.20	17.57	1.10	1.58	3.70	5.33
Glyceria aquatica	4.79	9.96	1.46	3.04	2.50	5.20	26.00	54.00	1.20	2.50	1.30	2.70	14.80	30.78
Phragmites communis	1.70	7.62	0.82	3.90	1.40	6.27	8.10	36.29	1.10	4.93	0.92	4.12	21.70	97.22
Acorus calamus	12.33	19.73	1.84	2.94	2.90	4.64	20.00	32.00	4.10	6.56	0.97	1.55	3.30	5.28
Sparganium crectum	10.11	12.94	2.10	2.69	3.90	4.99	24.80	31.74	6.80	8.70	3.60	4.61	6.80	8.70
Myosotis palustis	9.13	2.92	1.50	0.48	2.00	0.64	42.50	13.60	5.00	1.60	10.20	3.26	8.30	2.66
Mentha aquatica	16.95	28.48	1.58	2.75	2.20	3.70	10.50	17.64	6.90	11.59	3.10	5.21	4.10	6.89

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[a] Uptake figures given in mg/kg dry weight and mg/m^2 growth areas.

Criteria Development

In reviewing the information obtained in the background section, it was determined that two levels of acceptability were necessary because of the wide variation of toxicity concentrations reported in the literature. Directly applicable toxicity information is extremely limited, especially for waterfowl. Research is ongoing in this area. Several researchers active in this field were contacted to verify the apparent absence of waterfowl toxicity information in the literature (Appendix F). Because directly relevant information (waterfowl toxicity) was generally lacking, it was determined that conservative criteria should be used to define constituent levels known to be safe (Level 1).

Level 1 was established at extremely low concentrations to be harmless to relatively sensitive organisms. Criteria are based on toxicity information contained in the traditional scientific literature (mostly invertebrate LD_{50} data, which are highly variable), irrigation standards, and water quality standards set for livestock. It is anticipated that these conservative criteria can and will be adjusted as more relevant information is obtained, especially on waterfowl toxicity.

Level 2 criteria, levels that appear possible for waterfowl wetlands, are set at the highest concentration of each constituent that would still allow growth of desired marsh species (these include alkali, three-square, hardstem, and Olney's bulrushes, sago pondweed, spike-rush, and widgeongrass). Also used as a basis in establishing Level 2 criteria were water quality information at existing waterfowl refuges in the seven project States (Table 7) and information from natural geothermal springs (an average of parameter data from 23 springs in the seven project States--Appendix C lists areas used). Natural wetlands processes appear to be able to treat Level 2 parameter concentrations sufficiently to cause no significant environmental degradation when the effluents leave the wetlands.

RESULTS

Concentrations of each constituent were established on the basis described above and are listed in Table 8.

Table 7. Selected water quality parameters observed at western waterfowl refuges.[a]

									PARAMETERS (ppm)											
REFUGE	pH	TDS	Na	K	Ca	Mg	Cl	SO_4	PO_4	Al	Cd	Cr	Cu	Fe	Pb	Mn	Zn	NH_4	F	$CO_3(HCO_3)$
DEER FLAT (LAKE LOWELL), IDAHO	8.1	129							0.08									0.08		
COEUR D'ALENE LAKE, IDAHO	7.5	140	2		18	11	29	6	0.14		0.16		0.02		0.07	0.14	0.8	0.56	0.06	80
BLACKFOOT MARSH, IDAHO		431	13.5	4.1		26.5	17.2	35.3				1.08					0.46			
DESERT LAKE, UTAH	8.29	14,026	2,925	2.9	285	814	170	9,518												34.3(249)
OURAY NWR,[b] UTAH	6.88	790	96.2		118	52.4	48.6	296	0.2	0	0	0	0	0.11	0	0.41	0.01		0	
MEDICINE LAKE, MONTANA		14,000[c]																		
FREEZOUT, MONTANA		5,480			88	480	170	2,990						0					32	0(560)
BENTON LAKE NWR, MONTANA		3,126	147.3			122	45.5	362	1.93					0.12		0.01			2.57	
BOWDOIN NWR, MONTANA		7,000	2,400		40	350	220	5,400											0.5	
RED ROCKS NWR, MONTANA		100[d]																		
STILLWATER, NEVADA		780																		
SARASOTA H.S., NEVADA[e]	8.25	1,213	155	5.2	150	0.06	40	685												(15)
CARSON RIVER AT HWY 36, NEVADA[e]	7.8	220	225	3.2	25	6.8	10.7	29												0(120)
WELL 60N INCLINE VILLAGE, NEVADA[e]	7.76	2,693	480	11.5	280	5.2	90	1,680												(190)

[a] Source: Personal communications, listed in Appendix F.
[b] National Wildlife Refuge.
[c] Average of 5 measurements taken at Medicine Lake.
[d] Average of 13 measurements.
[e] Hydrothermal data collected and analyzed by CH$_2$M Hill (1979).

Table 8. Parameter specific criteria for hydrothermal effluent to be used in waterfowl wetlands.

Parameter	Level 1 (direct use) (ppm)	Level 2 (potential use) (ppm)	Average of 23 natural geothermal springs[a]
TDS	1,000	15,000	6,500
pH[b]	6.0	9.0	
Ag	0.003	0.5	0.04
Al	0.01	13.0	2.5
As	0.10	2.0	0.04
B	4.0	25	4.2
Ba	1.0	13.0	1.5
Be	1.0	12.0	0.04
Bi	ISD[c]	ISD	–[d]
Br	2.0	20	–
Ca	200	500	542
Cd	0.01	0.1	0.003
Cl	500	2,500	2,400
Cr	0.05	0.5	0.07
Cu	1.0	1.0	0.1
F	5.0	100	–
Fe	1.0	1.0	0.03
H_2S	0.07	1.0	–
Hg	0.007	0.12	0.006
I	2.85	28.5	–
K	5.0	200	86
Li	0.26	2.6	1.3
Mg	25	300	13.0
Mn	0.05	1.5	0.03
Mo	0.5	1.0	0.1
Na	500	1,400	1,350
NH_4	0.13	2.0	–
Ni	0.4	4.0	0.09
NO_3	90	420	–
Pb	0.15	1.5	0.04
PO_4	20	60	0.2
Ra	ISD	ISD	–
Rb	ISD	ISD	–
Sb	1.0	10.0	0.04
Se	0.05	3.5	0.12
Sn	2.5	25	1.5
SO_4	150	1,000[e]	167
V	0.1	1.0	0.23
Zn	0.2	5.0[e]	0.04

[a] See Table 1 for listing of sites used.
[b] Not in ppm.
[c] Insufficient data.
[d] No data available.
[e] Possibly higher.

DISPOSAL SITE SCREENING

INTRODUCTION

Section 5 examines the potential for each site designated in Section 3 to be used for disposal of geothermal effluent according to the criteria developed in Task 2.

METHODS

Initially, the parameters of each well or spring were examined. Well and spring data differ considerably, as do data between wells, depending on various conditions of sampling. Spring samples are useful for chemical constituent data because they may be qualitatively indicative of what the geothermal source will be like upon cooling and at atmospheric conditions. Alternatively, spring samples may be substantially different than the underlying geothermal source due to mixing with overlying waters and sediment.

If any particular site (well or spring) was found to have all constituents under Level 1 criteria, it was termed a "direct use" site. If not all constituents were of Level 1 standards but were between Level 1 and Level 2 criteria (or close to Level 2 criteria), the individual site was termed a "potential use" area. If any constituent concentrations were extreme, the site was considered to "need pretreatment" to reduce that concentration before use in a wetlands.

Sites were then grouped into geographic areas (county, township, and range) for each State (except Idaho and Montana, where areas are equivalent to counties). All areas were then determined to be capable of direct use on wetlands, potential use on wetlands, or in need of pretreatment due to probable toxic concentrations of one or more constituents (Tables 9-15).

RESULTS

Within the seven State project boundary, 21 areas were determined to be directly usable, 47 areas were determined to be of potential use, and 3 areas were determined to be in need of pretreatment. Not all areas could be adequately categorized in this manner, because sufficient data on effluent chemical composition were not always available. (Tables 9 through 15 identify these areas as "ISD," insufficient data.)

Table 9. Idaho geothermal use by area.

Area designation[a]	Site no.	County	Location water (twn,rg,Sec)	Source	Use in wetlands
Ada	1	Ada	3N, 2E, 11	W[b]	Direct
	2	Ada	3N, 2E	W	
	3	Ada	3N, 2E	W	
Madison	4	Madison	6N, 40E	W	ISD[c]
Adams 1	5	Adams	16N, 2E	S[d]	Direct
Blaine	6	Blaine	4N, 17E, 15	S	Direct
	7	Blaine	4N, 18E	S	
Boise	8	Boise	8N, 5E, 6	S	Direct
Camas	9	Camas	1N, 13E, 29	S	Direct
	10	Camas	1S, 13E, 34	S	
Cassia	11	Cassia	15S, 26E, 23	S	Potential
	12	Cassia	15S, 26E, 31	W	
	13	Cassia	15S, 26E, 23	W	
	14	Cassia	15S, 26E, 25	W	
Elmore	15	Elmore	4S, 10E	W	Direct
	22	Elmore	1N, 10E, 5	S	ISD
Gooding	16	Gooding	4S, 13E, 31	S	Direct
Franklin	17	Franklin	13S, 42E	S	Potential (Cl, K, Na may be problems in site 18)
	18	Franklin	15S, 41E	S	
Valley	19	Valley	1N4, 3E	S	ISD
Custer	21	Custer	11N, 15E, 19	S	Direct
Adams 2	20	Adams	15N, 1W	S	ISD
Washington	23	Washington	11N, 6W, 21	-	
	24	Washington	-	-	

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[a] Areas in Idaho are equivalent to counties. Area designation is county name.
[b] W = Well.
[c] ISD = Insufficient data.
[d] S = Spring.

Table 10. Montana geothermal use by area.

Area designation[a]	Site no.	County	Location water (twn,rg,Sec)	Source	Use in wetlands
Lewis & Clark	1	Lewis & Clark	12N, 6W, 32	W[b]	Potential[d]
	4		10N, 4W, 28	S[c]	
Jefferson	2	Jefferson	8N, 3W, 16	S	Direct
	3		5N, 4W, 10	S	
Madison	5	Madison	5S, 1W, 28	S	
	6	Madison	10S, 1E, 9	S	Potential[d] (H_2S may be a problem)
	7	Madison	4S, 7W, 28	S	
	8	Madison	3S, 2W, 6	S	
	9	Madison	3S, 1W, 14	S	
	10	Madison	2S, 6W, 1	S	
Park	11	Park	8S, 8E, 32	S	Potential
Meagher	12	Meagher	9N, 7E, 18	W	Potential[d]
Gallatin	13	Gallatin	2S, 4E, 18	S	Potential[d]
Deer Lodge	14	Deer Lodge	5N, 10W, 24	S	Potential[d] (H_2S may be a problem)
	15	Deer Lodge	3N, 10W, 2	S	
Sanders	16	Sanders	21N, 24W, 3	S	Direct (H_2S may be a problem)
	17	Sanders	18N, 25W, 9	S	
Beaverhead	18	Beaverhead	4S, 12W, 29	S	Direct (H_2S may be a problem)
	19	Beaverhead	5S, 15W, 25	S	

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[a] Areas in Montana are equivalent to counties. Area designation is county name.
[b] W = Well.
[c] S = Spring.
[d] Site or area developed.

Table 11. Nevada geothermal use by area.

Area designation	Site no.	County	Location (twn,rg,sec)	Water source	Use in wetlands
Churchill	1	Churchill	19N, 31E	W[a]	Potential
	2	Churchill	19N, 31E	W	
Elko 1	3	Elko	33N, 52E, 33	S[b]	Potential
Elko 2	4	Elko	34N, 55E	S	ISD[c]
	5	Elko	34N, 55E	S	
Eureka	6	Eureka	31N, 48E, 8	S	Potential[d]
	7	Eureka	31N, 48E, 17	S	
	8	Eureka	31N, 48E, 17	S	
	9	Eureka	31N, 48E, 17	S	
	10	Eureka	31N, 48E, 17	S	
	11	Eureka	31N, 48E, 17	S	
	12	Eureka	31N, 48E, 17	S	
	13	Eureka	31N, 48E, 17	W	
	14	Eureka	31N, 48E, 17	W	
Nye	15	Nye	11N, 43E, 7	S	Direct
	16	Nye	11N, 43E, 7	S	
	17	Nye	11N, 43E, 8	S	
	18	Nye	11N, 43E, 8	W	
	19	Nye	11N, 43E, 8	W	
Humbolt	20	Humbolt	36N, 40E, 29	S	Potential
Lyon	21	Lyon	15N, 25E, 16	W	Potential
	22	Lyon	15N, 25E, 16	W	
	23	Lyon	15N, 25E, 16	S	
	24	Lyon	15N, 25E, 16	W	
	25	Lyon	15N, 25E, 16	W	
	26	Lyon	15N, 25E, 15	W	
	27	Lyon	15N, 25E, 15	W	
Pershing	28	Pershing	28N, 32E, 33	W	Potential
Washoe 1	29	Washoe	32N, 23E, 10	S	Potential
	30	Washoe	32N, 23E, 10	S	
	31	Washoe	32N, 23E, 10	S	
	32	Washoe	32N, 23E, 10	S	

Table 11. (continued)

Area designation	Site no.	County	Location (twn,rg,sec)	Water source	Use in wetlands
Washoe 1	33	Washoe	32N, 23E, 10	S[b]	Potential
	34	Washoe	32N, 23E, 10	S	
	35	Washoe	32N, 23E, 10	S	
	36	Washoe	32N, 23E, 15	S	
	37	Washoe	32N, 23E, 15	S	
	38	Washoe	32N, 23E, 15	S	
	39	Washoe	32N, 23E, 15	S	
	40	Washoe	32N, 23E, 15	S	
	41	Washoe	32N, 23E, 15	S	
	42	Washoe	32N, 23E, 16	S	
	43	Washoe	32N, 23E, 16	S	
	44	Washoe	32N, 23E, 16	S	
	45	Washoe	32N, 23E, 16	S	
	46	Washoe	32N, 23E, 16	S	
	47	Washoe	32N, 23E, 16	S	
Washoe 2	48	Washoe	26N, 20E, 12	W[a]	Potential
Washoe 3	49	Washoe	26N, 21E, 6	W	Potential
	50	Washoe	26N, 21E, 6	W	
	51	Washoe	26N, 21E, 6	S	
Washoe 4	52	Washoe	19N, 19E, 25	W	Potential[c]
	53	Washoe	19N, 19E, 25	S	
	54	Washoe	19N, 19E, 26	W	
	55	Washoe	19N, 19E, 26	W	
	56	Washoe	19N, 19E, 26	W	
	57	Washoe	19N, 19E, 26	W	
	58	Washoe	19N, 19E, 26	W	
	59	Washoe	19N, 19E, 26	W	
	60	Washoe	19N, 19E, 26	W	
	61	Washoe	19N, 19E, 26	W	
	62	Washoe	19N, 19E, 26	W	
Washoe 5	63	Washoe	18N, 20E, 33	W	Some individual sites direct; others are potential
	64	Washoe	18N, 20E, 33	W	
	65	Washoe	18N, 20E, 28	W	
	66	Washoe	18N, 20E, 33	S	
	67	Washoe	18N, 20E, 33	S	
	68	Washoe	18N, 20E, 33	S	

Table 11. (concluded)

Area designation	Site no.	County	Location (twn,rg,sec)	Water source	Use in Wetlands
Washoe 5	69	Washoe	18N, 20E, 33	S[b]	
	70	Washoe	18N, 20E, 33	W[a]	
	71	Washoe	18N, 20E, 34	W	
	72	Washoe	18N, 20E, 34	W	
	73	Washoe	18N, 20E,	W	
	74	Washoe	18N, 20E,	W	
	75	Washoe	18N, 20E, 28	W	
	76	Washoe	18N, 20E, 28	W	
	77	Washoe	18N, 20E, 33	W	
	78	Washoe	18N, 20E, 32	W	
White Pine 1	79	White Pine	21N, 63E, 24	S	Direct
	80	White Pine	21N, 63E, 24	S	
Lincoln	81	Lincoln	4S, 67E, 4	-	May be direct; ISD[c]
Esmeralda	82	Esmeralda	1S, 36E	W	ISD
White Pine 2	83	White Pine	24N, 65E	W	ISD

[a] W = Well.

[b] S = Spring.

[c] ISD = Insufficient data.

[d] Site or area developed.

Table 12. New Mexico geothermal use by area.

Area designation	Site no.	County	Location (twn,rg,sec)	Water source	Use in wetlands
Hidalgo 1	1	Hidalgo	25S, 19W, 7	W[a]	Potential
	2	Hidalgo	25S, 19W, 7	W	
	3	Hidalgo	25S, 19W, 7	W	
	4	Hidalgo	25S, 19W, 7	W	
Hidalgo 2	5	Hidalgo	26S, 20W	W	Potential
Dona Ana	6	Dona Ana	23S, 2E, 34	W	Potential[b]
Grant 1	7	Grant	13S, 13W, 10	S[c]	Potential[b]
Grant 2	8	Grant	13S, 13W, 5	S	Potential
Catron 1	9	Catron	12S, 13W, 31	S	Direct
Catron 2	10	Catron	5S, 19W, 35	S	Potential[b]
Taos	11	Taos	24N, 8E, 24	S	Potential[b]
Sandoval 1	12	Sandoval	20N, 3E, 29	S	Direct[b]
	15	Sandoval	20N, 3E, 35	W	
Sandoval 2	13	Sandoval	18N, 2E, 23	S	Potential[b]
	16	Sandoval	18N, 2E,	S	
Sandoval 3	14	Sandoval	19N, 3E, 4	S	Potential
	17	Sandoval	19N, 2E, 13	W	
Socorro	18	Socorro	3S, 1W, 22	S	Direct[b]

[a] W = Well.

[b] Site or area developed.

[c] S = Spring.

Table 13. Northern California geothermal use by area.

Area designation	Site no.	County	Location (twn,rg,sec)	Water source	Use in wetlands
Lake	1	Lake	13N, 7W	S[a]	Pretreatment required (high B levels)
	2	Lake	13N, 7W	W[b]	
Lassen 1	3	Lassen	28N, 15E, 8	S	Direct
Lassen 2	4	Lassen	28N, 16E	W	ISD[c]
Lassen 3	5	Lassen	29N, 15E, 23	S	ISD
Lassen 4	6	Lassen	38N, 7E, 12	S	Direct
Modoc 2	7	Modoc	42N, 10E, 29	S	Potential
	10	Modoc	42N, 10E,	S	
	11	Modoc	42N, 10E, 29	S	
	12	Modoc	42N, 10E, 29	S	
Modoc 3	8	Modoc	42N, 17E, 6	W	Potential
Lassen 5	9	Lassen	38N, 8E, 15	S	Potential
Modoc 5	13	Modoc	39N, 5E, 9	S	Direct
Modoc 6	14	Modoc	44N, 15E, 23	W	ISD
Modoc 7	15	Modoc	43N, 16E, 12	S	Potential
Modoc 8	16	Modoc	45N, 16E	S	ISD
Modoc 9	17	Modoc	39N, 15E, 29	W	Potential
Modoc 10	18	Modoc	44W, 16E, 24	S	Potential
Mono	19	Mono	5N, 25E, 34	S	Potential
Napa 1	20	Napa	9N, 6W	S	Potential
Napa 2	21	Napa	9N, 7W, 26	S	ISD
Plumas 1	22	Plumas	22N, 14E, 13	S	Potential
Plumas 2	23	Plumas	22N, 14E, 13	S	Potential
Plumas 3	24	Plumas	21N, 14E, 32	W	Potential

[a] S = Spring.
[b] W = Well.
[c] ISD = Insufficient data.

BEST DOCUMENT AVAILABLE

Table 14. Oregon geothermal use by area.

Area designation	Site no.	County	Location (twn,rg,sec)	Water source	Use in wetlands
Lake 1	1	Lake	39S, 20E, 27	S[a]	Potential[b]
	2	Lake	39S, 20E, 27	S	
	6	Lake	39S, 20E, 4	S	
	7	Lake	39S, 20E, 4	S	
	8	Lake	39S, 20E, 4	S	
	9	Lake	39S, 20E, 27	S	
Lake 2	3	Lake	38S, 24E, 27	S	Potential[b]
	4	Lake	38S, 24E, 34	W[c]	
Lake 3	5	Lake	38S, 25E, 10	S	Potential[b]
Malheur 1	10	Malheur	38S, 45E, 20	W	Potential[b]
Malheur 2	11	Malheur	18S, 45E, 20	S	Potential[b]
Harney	12	Harney	37S, 33E, 15	S	Potential
	13	Harney	37S, 33E, 15	S	
Klamath 1	14	Klamath	38S, 9E, 28	W	Direct use[b]
	16	Klamath	38S, 9E, 33	W	
	17	Klamath	38S, 9E, 28	W	
	19	Klamath	38S, 9E, 28	W	
	20	Klamath	38S, 9E, 20	W	
	21	Klamath	38S, 9E, 33	W	
Klamath 2	15	Klamath	40S, 9E, 34	W	Direct use[b]
	18	Klamath	40S, 9E, 27	W	
Union	22	Union	3S, 30E -	-	ISD[d]

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[a] S = Spring.

[b] Site or area developed.

[c] W = Well.

[d] ISD = Insufficient data.

Table 15. Utah geothermal use by area.

Area designation	Site no.	County	Location (twn,rg,sec)	Water source	Use in wetlands
Beaver 1	1	Beaver	26S, 9W, 34	W[a]	Pretreatment required
Beaver 2	2	Beaver	30S, 12W, 21	W	Potential
	3	Beaver	30S, 12W, 28	W	
Millard	4	Millard	25S, 7W	W	ISD[b,c]
Beaver 3	5	Beaver	27S, 9W, 3	W	Pretreatment required[b]
	6	Beaver	27S, 9W, 3	W	
	7	Beaver	27S, 9W, 3	W	
Box Elder 1	8	Box Elder	9N, 3W, 27	W	Potential
Box Elder 2	9	Box Elder	10N, 2W	S[d]	ISD[b]
Sevier 1	10	Sevier	25S, 4W	S	Potential
Sevier 2	11	Sevier	25S, 3W	S	Potential[b]
	12	Sevier	25S, 3W	S	
Sevier 3	13	Sevier	22S, 1W	W	ISD
Iron	14	Iron	36S, 15W, 18	W	ISD
Salt Lake 1	15	Salt Lake	4S, 1W	W	ISD[b]
Salt Lake 1	16	Salt Lake	3S, 1W	W	ISD[b]

[a] W = Well.

[b] Site or well developed.

[c] ISD = Insufficient data.

[d] S = Spring.

WASTEWATER TREATMENT FEASIBILITY

INTRODUCTION

This section discusses the various methods of disposal of spent geothermal effluent (wetlands application, surface discharge, and injection), the advantages of each method, and the associated costs. Wetlands disposal is evaluated in the greatest detail, since the purpose of this study is to determine the feasibility of developing wetlands with geothermal effluent. Alternative means of effluent disposal are presented in order to compare the economics of wetlands disposal with other methods.

To use geothermal effluent for the development of wetlands suitable for waterfowl it is necessary to have a quality of effluent acceptable for wetlands disposal. Alternative disposal methods may also require an effluent quality level. Effluent that meets Levels 1 and 2 criteria--direct or potential use--may be used in wetlands without any or with relatively minor pretreatment (potential use areas may be controlled by State water quality regulations). Effluent that does not meet Level 2 criteria would need to be substantially pretreated to prevent toxic concentrations of constituents from degrading the ecosystem. Surface disposal requires that strict water quality standards be met before discharge is allowed to lakes or streams. Effluent to be injected does not have to be of a regulated quality, but it is often cost effective to reduce concentrations of constituents that scale or plug injection equipment.

EFFLUENT PRETREATMENT

Pretreatment of some geothermal effluent will be necessary to remove residual heat and/or high concentrations of specific toxic constituents before disposal of large quantities of wastewater. Methods of pretreating effluent to reduce temperatures are outlined below. Treatment technology for reduction of chemical constituents falls into two categories: those methods that require minimal expense and equipment (low technology), and complex systems that require large expenditures and trained operators (high technology). The various methodologies are described for both types of systems.

Temperature Reduction Pretreatment

All methods outlined below are based on the same process: primarily the evaporation of water. Evaporation requires latent heat transfer to convert liquid water to vapor. The following factors affect the evaporation rate: water, air, and wet bulb temperature; air speed; surface area; and volume of water to be cooled. Efficiency in cooling changes with variation in any of these factors. Each of the evaporative cooling methods described below is practical for cooling effluent.

Cooling towers. Mechanical draft cooling towers vary greatly in size and efficiency according to the complexity of design conditions. Their design is based on fixed air volume circulation, generated from fans moving at a constant velocity. The lowest cost unit for cooling 82° C water to 37° C at a flow rate of 1,500 gpm (at 37° C ambient temperature and 30% relative humidity) is a single cell, wood, induced-draft, splash-filled, cross-flow cooling tower.

Wood is often selected as the medium because the effluent to be cooled is often highly corrosive. Mechanical towers may require recirculation of water to keep the influent temperature constant.

Open pond. Open pond evaporation has three basic requirements: large acreage, a retaining wall (dike), and an impervious liner. The following equation gives a rough estimate of surface area required, assuming no channeling of flow.

Minimum surface area is derived by:

$$\text{Acres of surface} = \frac{(t_i - t_e)\ \text{gpm}}{8276.4(e_w - e_a)}$$

where: gpm = gallons per minute - influent

t_i = temperature of influent water - °F

t_e = temperature of effluent water - °F

e_w = vapor pressure of influent water - inches Hg

e_a = vapor pressure of wet bulb temperature of the air - inches Hg

The acreage determination using this equation is, at zero wind velocity, highly dependent on the wet bulb air temperature. Wind velocity increases evaporation and therefore decreases the required surface area.

Spray pond. This method substantially reduces the acreage of land required because of the increase in water surface area to water mass ratio. As a rule of thumb, a spray nozzle is required for every 50 gpm of effluent with a 6 psi (minimum) pressure drop across the nozzle. The following equation represents the minimum area for a lined spray pond.

$$\text{Acres of surface} = \frac{(t_e - t_i)\ \text{gpm}}{140{,}670(e_w - e_a)}$$

(All symbols are defined above.)

Wind velocities should be low in areas of spray pond cooling in order to minimize the potential of contamination in the surrounding area.

Open channel. This method, although not expected to be used directly, could be used in conjunction with other cooling methods for increasing heat loss efficiency from a geothermal source to a cooling tower or pond, before reaching the wetlands site. If the effluent is of sufficient quality, the channel could be unlined to keep costs down. The channel length required depends on a variety of conditions, including average wind speed in a geographic area, turbulence from small falls and rocks in the channel, ambient conditions, flow rate, and depth and width of the channel.

The following equations can be used to estimate the length of a channel necessary to cool effluent a desired amount.

$$\underset{\text{(ft)}}{\text{Length of channel}} = \frac{500\ \text{gpm}\ (t_e - t_i)}{95+0.425\ \frac{\text{gpm}}{7.48DW}\ (e_w - e_a)} W + 100$$

where: D = depth of channel in feet
W = width of channel in feet

(All other symbols are defined on page 6-3.)

Costs. Costs in Table 16 are based on cooling effluent of 1,500 gpm at 82° to 37° C at an ambient temperature of 37° C and 30% humidity. Costs for each method vary widely. Mechanical draft cooling towers range upward from $30,000, with increases resulting from high initial temperatures and flow rates. The estimate given is on the high end because of high incoming temperatures. Open pond and spray pond cooling system costs will vary according to flow rates, land costs, and the amount of earthwork required. The estimate given in Table 16 is also at the high end of the scale. Open channels appear to be the least expensive, most efficient means of lowering water temperatures to ambient temperatures. Cost estimates in Table 16 for open channels are for earthwork only. Land costs will vary the total cost of open channel cooling. Costs are in order of magnitude only. Not included in the cost estimate for any method are the costs of power to operate any cooling device, pumping costs, cost of lining for ponds, cost of sludge removal and disposal, or contingency and overhead costs.

Low Technology Pretreatment

The following methods are considered to be of low technological design for the removal or reduction of chemical constituents in geothermal effluent.

Temperature reduction. See the section on Temperature Reduction Pretreatment, page 6-2, for methodologies. Many metals and salts will precipitate out as temperatures drop to ambient conditions. Precipitate can then be removed in a sedimentation basin, by a filtration process, or chopped out.

Table 16. Comparison of cooling method costs.

	Cooling method			
Costs[a]	Mechanical cooling towers	Open pond[b]	Spray pond	Open channel
Initial cost	$65,000	$55,000	$35,000	$2.00/yd^3 [c]
Annual				
Operating	10,000	-	5,000	-
Maintenance	8,000	4,000	6,000	4,000
Life span (years)	10	40	40	40
Land area required (ft^2)	2,000	60,000	3,500	Variable

[a] Estimate does not include power costs, pumping costs, lining cost contingency or overhead costs and is estimated on a 1,500-gpm basis.

[b] Estimate does not include cost for solid waste disposal from evaporation pond.

[c] Based on unlined open dirt channel standard 8-foot width.

Aeration. Two common methods of introducing air into the flow stream are diffused aeration and mechanical aeration. Another aeration technique involves a tray-type aerator, where a vertical riser pipe distributes the geothermal effluent on top of a series of three or four trays, from which it then drips and spatters down. The tray-type aerator is commonly used to oxidize soluble ferrous iron (Fe^{++}) to insoluble forms of ferric iron (Fe^{+++}). The ferric iron then readily forms a hydroxide precipitate that settles out in a sedimentation basin or is removed by a filtration process.

Sedimentation. Sedimentation is a physical operation that removes settleable materials from liquids. It is a method used after waters have been chemically treated to precipitate. Settling ponds, tanks, or separators are generally used. The efficiency of the process is based on temperature of treated waters; size, amount, and character of particulates; and length of time for process to occur.

Filtration. Filtration is the process by which a liquid passes through a porous medium to facilitate the separation of solids from liquids (removal of particulates). The process is dependent on the particulate characteristics, filtering medium, filtration rate, and biochemical composition of the liquid medium. Several filtration systems are available (ranging from simple to complex) with efficiencies between 40 and 90% suspended solids removal. (For a detailed description, see Hartley 1978.)

Chemical precipitation. Use of lime to form insoluble metal hydroxides is considered state-of-the-art treatment for metals removal in the mining and milling industry. Levels of metals removal actually attainable are a function of lime dosage; operating pH; the presence of complexing agents, such as ammonia and organics; and the means employed to remove insolubles from the water. Softening includes a second treatment and flocculation step in which sodium carbonate is added to the water to remove calcium by precipitation as calcium carbonate. Adjustment of the pH from the 8.6 level used in the softening process may be required to produce an effluent with a pH suitable for discharge.

Lime softening produces a sludge that requires further compaction and dewatering before it is suitable for hauling to a final disposal site. The most acceptable dewatering method depends on the availability of land and expected net rainfall. Lagoon storage is generally used, but it can be quite expensive if land must be obtained.

Where sulfate levels are a problem, they can be reduced through treatment with sodium aluminate and lime. In this process, a calcium sulfoaluminate precipitate is formed that is removed as a sludge. This treatment, however, has been demonstrated only on bench scale level. Limited data available indicate that sulfate reduction is highly sensitive to the molar ratios of aluminum, calcium, and sulfate maintained in the reactor. Sodium aluminate precipitation, like lime precipitation, requires filtration, final pH adjustment (process operates at pH 12), and some method of sludge disposal, in addition to the actual treatment process. Current operating and maintenance costs for this treatment are about five times those of conventional lime softening. However, the cost may be reduced in the future as use of the process becomes more common.

pH adjustment. Neutralization of wastewaters that are excessively acidic or alkaline is a common practice. Lime or sodium alkalies are normally used to raise the pH. The most frequently used types are quicklime (CaO) and hydrated lime ($CaCOH_2$). These chemicals are less expensive than sodium alkalies, but they produce a considerable volume of sludge. Sodium alkalies such as caustic soda ($NaOH$) and soda ash (Na_2CO_3) neutralize acid and produce soluble neutral salts and little sludge.

Neutralization of alkalinity (lowering the pH) is normally accomplished with sulfuric (H_2SO_4), hydrochloric (HCl), or nitric (HNO_3) acid. Sulfuric acid is most commonly used.

Package treatment plants. Coagulation of colloidal suspensions or soluble metals (such as arsenic and iron) with iron, aluminum, or calcium salts is considered state-of-the-art treatment for metals in water treatment and the mining and milling industry. Following coagulation, the finely divided suspended matter is usually flocculated by physical mixing or chemical coagulant aids (such as activated silica, bentonite clay, or polyelectrolytes). The flocculated particles are then allowed to settle in a sedimentation basin before filtration in either pressure or gravity filters. The filters are required to strain out any flocculant metal oxides that were not heavy enough to settle out in the sedimentation basin.

These package plants require little operator attention, especially with a consistent influent water quality, which the geothermal water sources are expected to have.

Costs. Low technology treatment methods are relatively inexpensive. Aeration, sedimentation, pH adjustment, chemical precipitation, and filtration range from \$0.01 to \$0.06 per 1,000 gpm of flow. Package treatment plants incorporate most of the low technology methods and are readily available as factory preassembled units or field assembled modules that handle flows up to 1,400 gpm. At higher flows, these are not economically competitive. Cost for package treatment systems ranges from \$0.25 to \$0.40 per 1,000 gpm of effluent.

High Technology Pretreatment

The following methods are considered to be of high technological design for the removal or reduction of chemical constituents in geothermal effluent.

Reverse osmosis. Reverse osmosis (RO) involves the application of an external pressure to a solution in contact with a semipermeable membrane to force water through the membrane while excluding soluble and insoluble solution constituents. Extensive pretreatment and conditioning with respect to pH, temperature, and total suspended solids (TSS) levels are required for most successful RO operations. Filtration is usually required before RO to reduce interfering solids concentrations. Temperatures of the treatment stream above 100-120° F can cause increased rates of membrane degradation. Potential fouling problems associated with high concentrations of calcium or sulfate can limit the degree of concentration achievable in the brine or reject stream.

Brine from the RO process cannot be stored in an unlined pond because most of the constituents would resolubilize and eventually seep into the ground water. Disposal requires that the brine be concentrated further, using evaporation. A vapor compression evaporator (VCE) is often used for this purpose. Concentrated brine from the VCE can be further dried in a spray dryer and those dried solids disposed of in a landfill. The brine solids would almost certainly be considered a "hazardous waste" under the Resource Conservation and Recovery Act (RCRA) regulations.

Electrodialysis. The electrodialysis process employs a combination of semipermeable membranes to separate soluble impurities from water, and an electrical field to provide a driving force for ion migration through the membranes. The concentration limitations, pretreatment requirements, and brine disposal problems associated with reverse osmosis are also applicable to electrodialysis. Economies favor the use of electrodialysis for treating wastewater with a total dissolved solids (TDS) concentration of 1,000-1,500 mg/l. Reverse osmosis is favored at higher TDS levels.

Desalination. Two processes are currently being studied for removal of salts from seawater to make potable water. These are direct freezing/gas hydration and liquid-liquid extraction. Both methods are efficient in desalination at normal temperatures, although they are not economically feasible for larger volumes of water at high temperatures and will not be considered further. A detailed explanation of these processes can be obtained from the Office of Saline Waters.

Costs. The costs of pretreatment will be very site-specific. The combinations of elements requiring removal will greatly affect the technology used and the treatment's effectiveness. For example, lime softening may be required before reverse osmosis. Cost curves for pretreatment techniques are shown in Figures 2 and 3. Table 17 is a comparison of generalized efficiencies of the various methods of pretreatment. Table 18 recommends pretreatment processes for parameters that exceed Level 2 criteria for use in wetlands.

These cost estimates are based on the EPA publication, "Manual of Treatment Techniques for Meeting the Interim Primary Drinking Water Regulations," and are updated to 1980 costs (U.S. Environmental Protection Agency 1977; and Fluor Engineers and Constructors, Inc., 1978).

Solids from Pretreatment

Treatment of geothermal effluent could produce large amounts of sludge or solid waste that would require disposal. Solid waste obtained from evaporation and sedimentation ponds must be disposed of in a regulated manner. Federal and State laws pertaining to hazardous waste disposal may be applicable where significant amounts of heavy metals are present.

Regulations require burial or containment in an impermeable medium to prevent contamination of ground water. Most hazardous waste material is disposed of in a landfill designated to receive hazardous waste.

The cost of sludge and brine disposal will vary from area to area because of State regulations, landfill costs, hauling rates (based on road time and

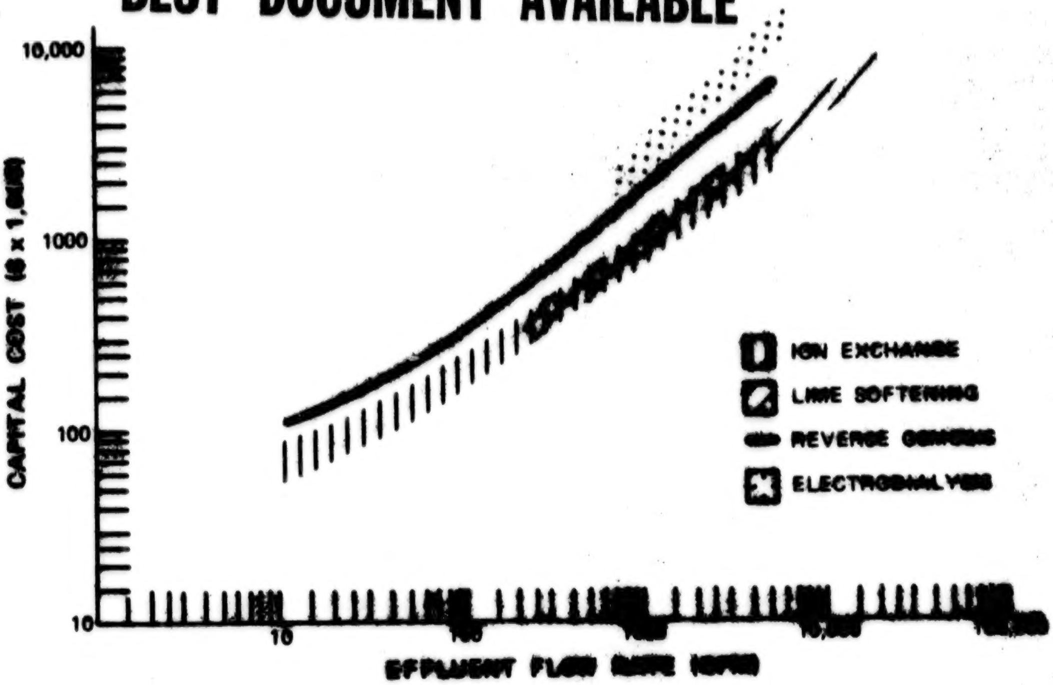

Figure 2. Pretreatment facilities construction costs.

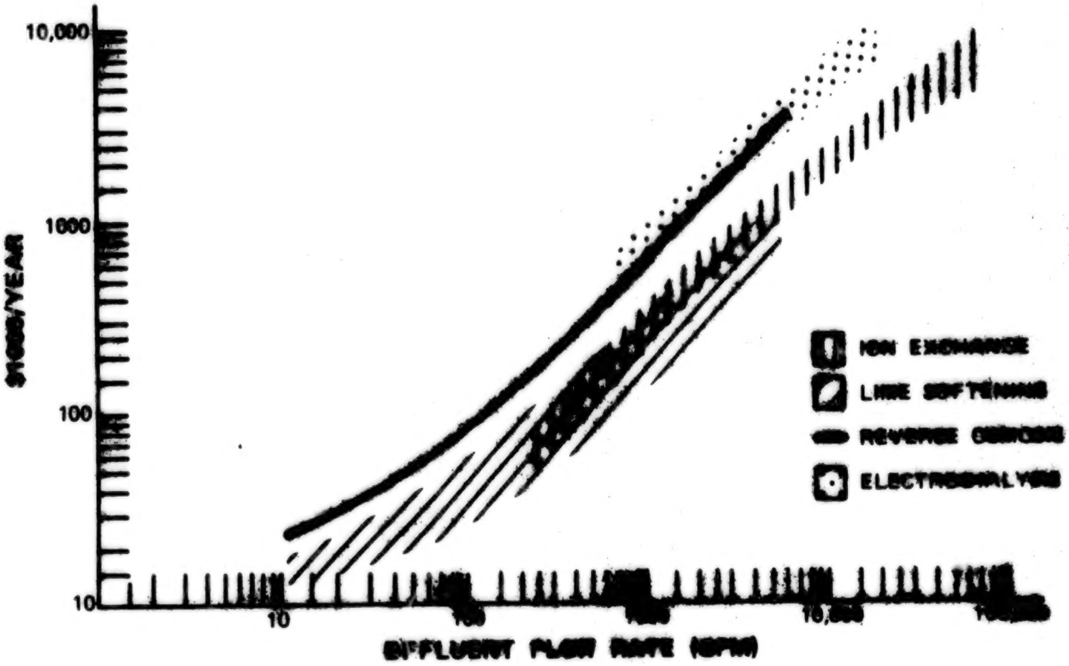

Figure 3. Annual cost of pretreatment facilities.

Table 17. Approximate efficiencies of pretreatment methods for removal of generalized constituents (Hartley 1978).

	Efficiency (%)	
Method	Total solids	Soluble metals
Temperature reduction	NA[a]	6
Aeration	NA	NA
Sedimentation	30	5
Filtration	85	85
Chemical precipitation	50	80
Package treatment plants	-	-
Reverse osmosis	90	90
Electrodialysis	40	35
Desalinization	98[b]	NA

[a] NA = Not applicable.

[b] Salts only.

Table 18. Parameters that exceed level 2 criteria (by state) and recommended treatment methods.

State	Constituents	Treatment methods
Idaho	Cl, K, Na, Li	Ion exchange or electrodialysis
Montana	pH; H_2S	Acid addition; aeration or chemical oxidation
Nevada	pH	Acid addition
	NH_4	Ion exchange, breakpoint chlorination
	K, Li, Br, B, Cl, Na	Ion exchange or electrodialysis
	H_2S	Aeration
	Fe	Aeration or lime-soda softening
	As	Ferric sulfate coagulation, alum coagulation, or excess lime softening
New Mexico	pH	Acid or base addition
	Fe	Aeration or lime-soda softening
	As	Ferric sulfate coagulation, alum coagulation, or excess lime softening
	Li, SO_4	Ion exchange
Northern California	H_2S	Aerate, chemical oxidation
	B, Li	Ion exchange, electrodialysis
Oregon	As	Ferric sulfate coagulation, alum coagulation, or excess lime softening
	H2S	Aerate, chemical oxidation
Utah	TDS	Reverse osmosis
	B, C, L,	Ion exchange electrodialysis
	K, Na, NO_3	

quantity) and distance to the disposal site. Cost estimates for only the labor required to remove the dry solids from drying beds include approximate man-hour and machine-hour time. For approximately 100 tons/year of dry solids, costs would range from $35 to $60/hour for 30 hours of labor. For approximately 1,000 tons/year, costs remain the same for 55 hours of labor.

EFFLUENT DISPOSAL TO WETLANDS

Wetlands can be created or natural wetlands enhanced with spent geothermal effluent. Disposing of the geothermal effluent in this manner has such advantages as creating waterfowl habitat or prolonging it in areas with limited water supply. Pretreatment for disposal of effluent also would not need to be extensive because of the wetlands' natural treatment capabilities and the potential for cascading use of effluent (if the effluent leaving the wetlands may be used for some other purpose, such as irrigation). (EPA standards for discharge might be relaxed for wetlands under a "novel treatment techniques" regulation.) Treatment capabilities of wetlands and cascading uses of effluent are presented below along with an outline of general site identification, ecological design criteria, and marsh construction and maintenance costs. Ecological design criteria are based on a managed marsh for optimal waterfowl usage and may be scaled down for other types of waterfowl areas.

Treatment Capabilities

Wetlands have recently become recognized as valuable natural sinks for contaminants of industrial or municipal origin. Studies are currently investigating the uptake characteristics of wetlands, including both vegetational and soil capabilities that contribute to the detoxification of wastewater (Williams and Works 1977). This transformation of elements into less harmful compounds often improves the water quality of the effluent (Richardson et al. 1976). Discussed below are the capabilities of wetland soils and vegetation for treatment of various effluents. A general discussion then summarizes the potential for treatment of geothermal effluents by wetlands.

The soil/water interface is the major site of adsorption or deactivation of contaminants in the marsh-wetlands system (Turner et al. 1976). While in the liquid phase in the soil, compounds and elements are subjected to a variety of interactions such as adsorptive bonding, precipitation, dissolution reactions, biological decomposition, and turnover reactions. Compounds only accumulate in the soil after binding has occurred on soil solids. This phenomenon is greatly dependent on the particular ionic form of the compound. Soils have the ability, depending on pH and chloride content, to alter divalent cations to monovalent cationic, uncharged, or even negatively charged compounds (deHaan 1976). In this manner, accumulation can be controlled so sorption capacities are not exceeded (Richardson et al. 1976). Wetlands have a high rate of soil production, especially organic soils derived from their high rates of vegetation growth.

The soil type to be used in the wetlands will determine the capacity to take up and bind contaminants in the soil (deHaan 1976). The fact that highly organic wetlands soils with a large accumulation of litter can act as a major sink for nutrients (mainly nitrogen and phosphorus) has been well recognized

(Richardson et al. 1976). Recent studies have shown that heavy metals can be bound tightly to organic soil particles and, therefore, become unavailable for uptake by vegetation. Organic marsh sediments appear to be a good sink for heavy metals. Concentration of metals that can be held varies with the percent organic matter in the soil and the sediment size (Valiela and Teal 1974). Concentration of a particular metal is also a function of ion exchange capacity of the system (deHaan 1977).

Lead, for example, binds to sulfide-rich sediments, while zinc and cadmium are taken up by sediments via adsorption and ion-exchange capacities (Valiela and Teal 1974). Accumulation of lead, zinc, and cadmium is entirely limited to the upper 30 to 40 cm of soil, with the highest concentrations limited to the upper 5 cm of organic soils (deHaan 1977).

Sandy soils in marshes do not bind nutrients appreciably, allowing vegetation free uptake of contaminants. Consequently, sandy soils do not readily become polluted from added wastes. For example, phosphorus (from wastewater) is readily leached in sandy wetlands and is therefore readily available (Richardson et al. 1976).

In sandy clay soils, a 99% phosphorus removal efficiency is obtained with a wastewater loading rate of 2 inches per day (deJong 1976). A removal efficiency of 80% total nitrogen is obtained in the same soil type. The purification process is clearly related to the retention time, percolation rate, soil type, loading rate, and holding capacity, as well as the vegetational species composition that grows on the particular soil type (Lindsley et al. 1976).

Wetlands vegetation seems to be generally tolerant of pollution inputs. Numerous pilot programs currently being conducted indicate the high capacity of vegetation for the purification of sewage and industrial wastewater. Lower costs are also associated with wetlands disposal of wastewater, compared with chemical techniques (Williams and Works 1977). Both sewage and industrial wastewater contain sufficient amounts of constituents similar to those found in geothermal effluents. It is assumed that marsh plants would act in a similar manner whether geothermal or industrial wastewater was used.

Czerwenka and Seidel (1976) state that marsh plants can act as vertical pipes in the removal of contaminants. Almost all compounds, toxic or not, are taken up at low concentrations, with some compounds accumulated at an order of magnitude greater than the concentration in the water in which the plants are growing. The rate of accumulation varies widely according to species; phenological states of the same species; growth rates of individuals; and allocation patterns to roots, leaves, stems, and inflorescences of an individual plant (Lindsley et al. 1976). Accumulation is also dependent on physical factors such as soil interactions, water depth, climate, duration of exposure, and numerous other environmental aspects (Czerwenka and Seidel 1976).

Most wetlands uptake investigations to date have dealt with nutrients found in wastewaters, predominantly nitrogen and phosphorus uptake. These two compounds can have striking effects on plant productivity when applied in large quantities to ecosystems (Ewel 1976). Both compounds are essential nutrients for proper nutrition and are usually limited in normal soils, consequently the addition of large amounts of nitrogen and phosphorus in wastewaters can increase net primary productivity up to 50% (Turner et al. 1976).

When sewage effluent is first applied to emergent vegetation plots, the initial removal of nitrogen and phosphorus is high, but it quickly drops to zero as the supply exceeds the uptake capability (deJong 1976). Scirpus validus (softstem bulrush) can remove 31% of the total phosphorus concentration in an artificial marsh irrigated with sewage effluent, while it gains only a small fraction of measurable phosphorus (Spangler et al. 1976). Phragmites sp. (reed), when grown in wastewater, increased 13% in measurable phosphorus, with a concomitant 55% increase in biomass (Turner et al. 1976). Lemna minor (duckweed) has been shown to have phosphorus concentrations of up to 12,000 ppm (Ewel 1976). At the Porter Ranch peatland study in Michigan, uptake of phosphorus proceeded to 90% within 3 hours after application (Kadlec et al. 1977). Removal of nitrogen and phosphorus in the 30-90% range is common in almost all studies currently ongoing.

Uptake and accumulation of other contaminants (e.g., heavy metals, and boron) have not been as well documented as those of the major nutrients. Current experiments at Raft River, a KGRA in Idaho, indicate no substantial problems with increased metal content in crops irrigated with geothermal effluent (Stanley 1979).

It appears that concentrations of contaminants, normally thought to be toxic, can be trapped in the walls of cells without damaging the vital cell functions, allowing high accumulation of many contaminants (McNabb 1976). Submergent plant species provide the best known example of this phenomenon.

Submergent species lend themselves well to efficient removal of contaminants, as accumulation is largely through the foliage (directly into leaves), but these species still possess the capability to absorb from sediments through the root system. When growing at a maximum rate, submersed plants can concentrate elements $0.5\text{-}1.0\times10^4$ times greater than the concentration they are grown in without toxic effects.

Lemna minor is an accumulator of boron, a highly toxic substance to aquatic animals, concentrating it in excess of one order of magnitude greater than the range in which it is found. On a dry weight basis, boron has been found in tissue up to 90 µg per kg of tissue (McNabb 1976). Lemna minor and Eichornia crassipes (water hyacinth) complement each other in contaminant removal in temperate climates, because one accumulates compounds the other does not (Small 1976). Table 19 shows the heavy metal removal ability of two species of marsh plants, Eichornia crassipes and Alternanthera sp. (alligator weed) (Wolverton et al. 1976).

Emergent species also accumulate high concentrations of contaminants, but absorption occurs via the root system with little to no direct absorption into the leaves. Little translocation of toxic substance occurs from the roots to leaves in most plant species, and storage takes place in below-ground parts. Spartina sp. (cordgrass), Schoenoplectus sp. (European bulrush), Scirpus sp. (bulrush), Typha sp. (cattail), Phragmites sp., and other marsh species have

Table 19. Capability of Alternanthera Sp. (alligator weed) and Eichornia Crassipes (water hyacinths) to remove various heavy metals from polluted waters, (Wolverton et al. 1976).

Metal (ionized form)	Alligator Weed		Water Hyacinth	
	Lab experiment[a] (mg)	Field potential[b] (kg)	Lab experiment[a] (mg)	Field potential[b] (kg)
Cadmium	-	-	0.67	0.161
Lead	0.10	0.024	0.176	0.042
Mercury	0.15	0.035	0.150	0.036
Nickel	-	-	0.50	0.12
Silver	0.44	0.106	0.65	0.156
Cobalt	0.13	0.031	0.57	0.137
Strontium	0.16	0.038	0.54	0.13

[a] Quantity removed, absorbed, or metabolized per gram dry plant weight per day.

[b] Quantity removed, absorbed, or metabolized (kg) per acre per day.

been used in experimental plots to assess the ability of each to remove contaminants. In one such experimental plot in Louisiana, Scirpus validus exhibited identical concentrations of molybdenum, barium, and calcium between control and experimental plots. Concentrations tended to be greater in experimental plots over control plots for calcium, manganese, strontium, molybdenum, sulfur, and barium in Scirpus falcata and Scirpus patens. Seasonal trends of experimental plots tracked control plots but at higher concentration levels for iron, potassium, and zinc in Scirpus patens (Turner et al. 1976).

Vegetation also acts to modify the pH of wastewater. Roots of Schoenoplectus lacustris will rapidly (in less than 4 days) neutralize acid or alkaline sewage, resulting in optimal chemical nature of water and improved water quality (Seidel 1976).

Purification of wastewater by wetlands systems (e.g., marshes, swamps, and wet meadows) has been shown to occur in all pilot programs currently in existence (see Table 20 for influent vs. effluent characteristics of a wetlands used for wastewater treatment). Not only can vegetation accumulate toxic substances and neutralize pH, it also oxygenates effluent water for improved water quality (Seidel 1976). Lemna minor serves as an oxygenator of water and can tolerate winter temperatures in mild climates (Small 1976). Scirpus sp. also is effective at reducing biochemical oxygen demand (BOD) of sewage effluent up to 81% (Spangler et al. 1976). This is extremely important in the proliferation of aquatic faunal species.

Zooplankton populations help to maintain water clarity, as they forage on the algal species that tend to cloud the water (McNabb 1976).

In most wetlands treatment systems, some form of vegetation harvesting is employed to maintain water quality. Therefore, it is often desirable to remove vegetation from the system before accumulated contaminants are released to the water (Whigham and Simpson 1976). (Contaminants are often released as plants become dormant.)

In order to prevent this release, plants are harvested a month before the end of the growing season, at a maximum standing crop. Each marsh species follows a typical pattern of growth that dictates when harvesting should occur. This will vary, of course, according to the climate of the region. Flushing of a marsh system will also cause the release of stored materials; therefore, this factor should be taken into account in the design criteria (Small 1976).

Although harvesting is recognized as a necessity for maintaining low levels of contaminants in some wetlands systems, harvesting can cause successional changes. Successional changes brought about can alter marsh structure (Ewel 1976; Small 1976; Whigham and Simpson 1976). Alteration of marsh structure can affect what waterfowl species will utilize the area. A rotation of species harvested might prevent major alterations in the marsh-wetlands. In some wetlands, harvesting can delay successional changes by delaying the natural filling rate of the wetlands. The effect of harvesting vegetation on the wetlands is not simple and is difficult to predict.

Community composition is definitely altered by the addition of chlorinated effluent. Chlorinated effluent changes vascular plant species composition;

Table 20. Comparison of influent vs. effluent charactertistics of wastewater treated by wetlands in New York (average values over a 13-month period) (Small 1976).

	Concentration (ppm)					
	Average		Maximum		Minimum	
Parameter	I[a]	E[b]	I	E	I	E
pH	6.8	6.9	8.9	9.2	4.8	6.1
Calcium	20	14	72	47	12	9
Chloride	35	29	110	85	25	17
Chromium	0.05	0.02	0.5	0.3	0.01	0.01
Copper	0.7	0.04	3.2	0.2	0.2	0.01
Fluoride	0.5	0.3	1.0	0.5	0.2	0.2
Iron	3.6	1.5	20.1	3.9	0.8	0.3
Magnesium	4.3	3.3	8.5	4.4	3.4	2.3
Manganese	-	0.1	-	0.5	-	0.03
Potassium	4.9	3.11	11.	11.	2.	0.9
Sodium	26.4	22.8	52.	30.	18.2	15.7
Zinc	1.3	0.2	4.0	0.7	0.3	0.06

[a] I is an abbreviation for influent (polluted waters).

[b] E is an abbreviation for effluent (treated waters).

perennials are mostly unaffected, but annuals can be regulated by effluent application. Some annual species are completely eliminated (i.e., Impatiens sp. and Bidens sp.) (Whigham and Simpson 1976). Since existing wetlands would experience composition alteration with the addition of effluent, artificial wetlands seem preferable to enhancement of natural wetlands (Williams and Works 1977).

Wetlands treatment of sewage sludge, wastewater, industrial wastewater, and dredged spoils has been demonstrated as extremely effective (Ewel 1976; Richardson et al. 1976; Small 1976; Wolverton et al. 1976; Kadlec et al. 1977; Williams and Works 1977). The maximum amount of contaminants that can effectively be treated by wetlands is, as yet, unknown (Valiela and Teal 1974). Judging by the ability of soil and vegetation to complex, alter, or store contaminants, the prospect of using wetlands for treating geothermal effluents is very promising. Conversely, using spent geothermal effluent to create or enhance wetlands for waterfowl and other birds is also very promising. Table 21 presents various wetlands species and summarizes their ability to treat wastewater. Wastewater can be purified by filtration into the soil, with vegetation used as a tool to protect the longevity of the soil system (deJong 1976; McNabb et al. 1976). Because wetlands have high vegetation growth rates, they usually have high soil production rates. These high soil production rates tend to prevent excessive concentration buildups of metals and other elements within the soils. This is especially true of permanent wetlands, compared with seasonally wetted wetlands. Managed wetlands can be even more efficient in effluent removal. A managed artificial wetland is a foreseeable goal in attaining maximum treatment of geothermal effluent while providing excellent waterfowl habitat in arid areas.

Cascading Uses

A cascading use (a succession of uses) with great apparent potential is irrigation for wildlife management or commercial purpose. Water for irrigation is in short supply in much of the western United States. Spent geothermal effluents may be an alternative water source if the subsequent quality is acceptable after leaving the wetlands, and if the wetlands is near irrigable land or if the spent effluent is of high quality and near irrigable land.

Depending on the quality of the geothermal effluent, it may be suitable for irrigation use either before or after entrance to the wetlands. Only the best quality effluents could be used before wetlands. The best application for high-quality effluent may be to irrigate uplands directly adjacent to the wetlands, with the effluent allowed to run off into the wetlands. Grains suitable for wildlife feed might be grown to further enhance wildlife production. Commercial agriculture would not be feasible in many instances because of reduced crop yields, resulting from the use of the relatively poor quality (for irrigation) water. Also, most commercial irrigation systems are designed to minimize runoff, which would result in very little effluent for wetlands enhancement. However, it is suspected that many western farmers would be willing to use less efficient irrigation systems if these waters were available.

Table 21. Potential aquatic plants and animals for use in wetlands for the treatment of wastewater, (Stowell 1979).

Organism	Probable role and remarks
Floating aquatic plants	
Eichornia crassipes (Water hyacinth)	Its extensive root system serves as a mechanical filter and a support structure for bacteria. The plant itself accumulates nutrients and heavy metals. Mats of hyacinth attenuate sufficient light to limit the growth of algae. Water leaving hyacinth mats is devoid of oxygen, typically. Hyacinths will not winter-over in temperate climates. Water hyacinths are potential aquatic pests.
Lemna minor (Duckweed)	This small plant accumulates nutrients and heavy metals, particularly the latter. It also attenuates sufficient light to hinder the growth of algae. Ubiquitous in the United States, duckweed is not considered a major aquatic pest. Wind can disrupt duckweed mats. Duckweed can survive throughout the winter in milder temperate climates.
Emergent aquatic plants	
Typha sp. (Cattails)	The submerged portion of a cattail stand serves as a mechanical filter and a support structure for bacteria. These plants accumulate nutrients and probably heavy metals. Algae will not grow in dense cattail stands; however, water leaving stands is aerobic, typically. Cattails successfully winter-over, even in harsh climates. Cattails may be useful as a windbreak for duckweed.
Scirpus sp. Schoenoplectus sp. (Bulrush)	Essentially as noted above for cattails. Bulrushes will accumulate heavy metals and may be more adaptive than cattails to wastewater environments.
Phragmites sp. (Reeds)	Reeds are similar to cattails and bulrushes but tend to grow in less dense stands. The "hollow tube" structure of reeds may make these plants more durable where substrate root-zone conditions are anaerobic.

Table 21. (concluded)

Organism	Probable role and remarks
Submerged aquatic plants	
Algae	This broad grouping of unicellular plants accumulates nutrients and dissolved salts into settleable algal solids. Photosyntesis occurs, resulting in the release of free oxygen into the water at the expense of increasing the BOD of the water. Blue-green algae may increase the nitrogen content of the water. Various forms of algae will grow throughout the year in open water.
Potamogeton sp. (Pondweeds)	These plants accumulate nutrients and heavy metals. The value of pondweeds as support structure for bacteria is variable from species to species, as is the potential to compete with and shade out algae. Because these plants are for the most part submerged in the wastewater environment, there is greater inherent chance of upset.
Other possible aquatic plants	
Myriophyllum sp. (Watermilfoil) Azolla sp. (Water velvet) Ceratophyllum (Coontail) Alternanthera sp. (Alligator weed) Filamentous green algae Stoneworts	All aquatic species have wastewater treatment potential. The answer to the question "Which to use?" will depend on its treatment potential and function in a given system. Use of these plants will also depend on whether they will become aquatic pests.

Using the effluent to create a wetlands and then using wetlands discharge water for irrigation seems more generally applicable than using the water for irrigation before the wetlands. Water that has been detained in wetlands before being used for crop irrigation will have a significant percentage of the elements it carries adsorbed and absorbed by the wetlands soils and plant life. This polishing effect has the potential to greatly reduce many specific ion and trace element toxicity problems and to allow the water to be subsequently used to irrigate a greater variety of less salt-tolerant crops. Less water will be available, however, because of evapo-transpiration losses.

The amount of land that could be irrigated with geothermal effluent depends on the crop and soil types, and especially on the climate. The peak water use for grain, for example, ranges from 2.8 gpm/ac for a cool climate to 7.6 gpm/ac for a low desert climate. For the same climate ranges, pasture grasses and alfalfa require from 3.8 to 8.8 gpm/ac. The costs for irrigation systems range from $500 to $2,000/ac, excluding land cost (Fereres et al. 1978).

The quality of geothermal effluent water will change with every site and even with different uses at the same site. Because of this variation, some effluent will be satisfactory for irrigating a variety of crops and some may need pretreatment before it can be used, even on highly tolerant crops. Recommended maximum levels of effluent constituents for irrigation are given in Table 22.

If the recommended maximum levels are exceeded slightly by a few elements, it may still be possible to use the water for irrigation of tolerant crops, with special management. However, a high concentration of only one element (e.g., boron) may make the effluent toxic to all crops; therefore, each situation should be analyzed individually. Less common elements that are not shown on Table 19 but that may be present in geothermal effluent in significant concentrations will also require special analysis.

A 3-year research project on irrigation with geothermal effluent is being completed on the Raft River project in Idaho (Stanley 1979). The preliminary results indicate that the Raft River effluent can be used in commercial agriculture, provided that specialized crops (salt-tolerant, such as barley, forage grass, and alfalfa) and management practices are used. Special management requirements include the following.

- Providing frequent irrigations to maintain adequate soil moisture.
- Using extra water to satisfy leaching requirements.
- Using surface rather than sprinkler irrigation methods.
- Using special planting techniques.
- Applying organic residues and gypsum to maintain soil permeability.

Table 22. Water quality requirements for irrigation water (University of California Cooperative Extension 1975).

Constituent	Maximum Levels Recommended	
Salinity as electrical conductivity	3,000-8,000 µmhos/cm	
TDS	2,000-5,000 mg/l	
Sodium as SAR	9	
Element	69 mg/l--sprinkler applied water	
Chloride	106 mg/l--sprinkler applied water	
pH	Normal range = 6.5-8.4	
	For waters used continuously on all soil (mg/l)	For use up to 20 years on fine textured soils of pH 6.0 to 8.5 (mg/l)
Aluminum	5.0	20
Arsenic	0.10	2.0
Beryllium	0.10	0.50
Boron	0.75	2.0
Cadmium	0.010	0.050
Chromium	0.10	1.0
Cobalt	0.050	5.0
Copper	0.20	5.0
Fluoride	1.0	15.0
Iron	6.0	20.0
Lead	5.0	10.0
Lithium	2.5	2.5
Manganese	0.20	10.04
Molybdenum	0.010	0.050
Nickel	0.20	2.04
Selenium	0.020	0.020
Vanadium	0.10	1.0
Zinc	2.0	10.0

The electrical conductivity of the Raft River geothermal effluent averages about 3,100 µmhos/cm. The pH, Cl, $CaCO_3$, and SiO_2 of the geothermal effluent were not statistically higher than control irrigation wells. The fluoride content (9.4 mg/l), however, was about five times higher than normal irrigation supplies, and is of special concern for its effects on livestock that may be fed the crops. The third year of research, which has yet to be reported, will explore fluoride in more detail.

Another water quality consideration with geothermal effluent is temperature. Crops (and plants in general) cannot tolerate prolonged contact with water in excess of 40° C. To cool primary effluent water, it may be possible to use a fine mist sprinkler irrigation that will allow the water to cool before it contacts the plants, or to use cooling towers or ponds to cool the water before irrigation or entrance to the managed marsh area (see Effluent Pretreatment Section). Water of any temperature (0° C to 100° C) will reach the wet bulb temperature of the surrounding air if sprayed in a fine mist for more than 20 feet through the air. Irrigation by any method with warm water has no effect on the length of the growing season, since that is affected mainly by air temperature.

It now appears that direct effluent from almost all areas of geothermal development is unsuitable for irrigation without pretreatment or special crop selection and irrigation management. However, the polishing effect of wetlands appears to increase the potential for irrigation as a cascading use after the wetlands. A second major reason for irrigation after the wetlands would be in instances where the wetlands effluent is unsuitable for discharge to a stream. Rather, the effluent could be used up by evapotranspiration and percolation in the irrigated field, leaving little or no effluent for discharge (e.g., land disposal). Irrigation before wetlands use would apparently be infeasible for most of the geothermal sources, assuming that pretreatment would not be used only to make the effluent quality suitable for irrigation.

Aquaculture accounts for only 3% of U.S. fish production (estimates from McNeil 1978). One of the major constraints to development of this industry is the availability of low-cost heated water of adequate quality and quantity. Wastewater from geothermal developments could be used to enhance the expansion of this industry. In turn, aquaculture could provide suitable disposal of excess wastewater.

Other potential cascading uses could include industrial and recreational uses (such as food drying or hot springs), greenhouse applications, harvest of vegetation for livestock feed or methane generation, and establishment of riparian vegetation along conduit systems. Industrial use of geothermal effluents would depend on water quality, temperature, and proximity to labor markets.

Virtually all the sites identified for potential geothermal wetlands developments would be suitable for any type of cascading use. Sites with high flow rates could possibly support several uses, as well as a wetlands.

General Site Identification

Geothermal effluents could be used to enhance or create wetlands on about any relatively flat, open space area; however, costs and problems can be minimized if the following general guidelines are used.

Location. The distance from the geothermal source to the wetlands can be greater for larger flows. The following limits are suggested.

- 100 gpm, up to 2 miles.
- 1,500 gpm, up to 3 miles.
- 30,000 gpm, up to 12 miles.

Topography. The costs of creating wetlands would be excessive on moderately to steeply sloping areas because of the need for large amounts of earthwork. The following slopes are suggested.

- For creating ponded areas, 0 to 3% slope.
- For overland flow, up to 12% slope.
- Areas with mounded microrelief are preferred, as they provide a desirable intermix of wet and dry areas.

Soils. The soil type affects the cost and feasibility of dike construction, the treatment capacity of the wetlands, and the drainage characteristics.

If diking is required, peat and muck soils should be avoided because they are difficult to work with. Structurally stable soils should be used for diking to minimize the need for riprap.

The following parameters should be investigated to establish soil suitability.

- Texture of the soil profile influences moisture-holding capacity and adsorption reactions between soil and waste constituents. Fine-textured soils contribute to slow water movement and ponding. A certain amount of colloidal fines is desirable to increase the sorption and fixation capacity of the soil for potential pollutants, but too great a percentage of fine-textured particles can raise the possibility of surface runoff and contamination. Organics with a high cation exchange capacity will provide treatment for heavy metal pollutants. Soil profile permeability influences the soil infiltration and subsurface permeability rate, moisture-storage capacity, and retention time of effluent applied to soils.
- Adequate soil depth is important for root development and retention and removal of effluent constituents. The soil has a finite capacity to store nutrients for plant uptake, retain heavy metals, and hold salts. The capacities are a function of the soil mass and the retention time of the waste constituents in the soil. Shallow soils have

a reduced capacity to retain potential pollutants. Therefore, soils shallower than 2 feet over bedrock are considered unsuitable for development.

- Soil drainage classes indicate the degree of internal drainage of moisture through the soil profile. Excessive drainage will allow rapid movement of dissolved effluent constituents. The most desirable drainage classes are described as moderately slow to very slow.

- Erodibility, as well as steepness of the slope, is used to evaluate the potential for erosion. Erodibility is a function of particle size and aggregate stability of the soil. The potential for surface water pollution from effluent constituents is greater from soils of high erodibility. Also, cultivation of forage crops is difficult on soils that are severely eroded, as less desirable subsoils may be exposed.

- Flood-prone areas are undesirable for effluent discharge because of the highly variable drainage conditions and the high potential of contamination of surface waters. Floodplains would need to be highly managed for water control facilities and wetlands vegetation, which could prove to be economically infeasible.

- Soil salinity influences water movement in the soil and the capability of continued vegetation and forage production. Soils with high salinity before wetlands development should be carefully considered, because high evaporation rates (a major factor in disposal) coupled with high salt concentration in effluents will greatly affect soil properties.

Ground water. The ground water must be considered during potential site identification. Whether the site is in a ground water recharge or discharge area, the rate and direction of ground water movement, the quality, and the uses of the ground water must all be determined and evaluated. The effects on the ground water of using an area for creation or enhancement of wetlands will usually require very site-specific investigations to determine site suitability and mitigating design/operation measures.

Surface water. The following surface water conditions should be evaluated.

- Floodplains can be used if economically protected, or if periodic flooding will not damage the wetlands habitat and water control facilities. Also, the effect of untreated geothermal effluents being mixed with floodwaters must be considered.

- Existing wetlands that would benefit by an additional water source or a more controlled supply would be suitable.

- The feasibility of discharge of treated effluent from the wetlands into surface waters must be evaluated. Costs will normally be lower where discharge is allowed.

Land use. The following should be considered.

- Areas near airports should be avoided where wetlands would cause an influx of birds.
- Areas near agricultural lands should be avoided to prevent crop depredation by an influx of waterfowl.
- Existing open spaces should be most suitable. High-value, developed lands should be avoided.
- Areas with cultural or natural resource value should be considered only if wetlands would protect or further enhance the resources.

Ecological Design Criteria

The following outline presents major objectives and considerations for engineering design criteria of managed wetlands. The purpose of this section is to suggest biologically based considerations for design that will be weighed with other discipline constraints and objectives to develop the best and most practical design criteria. These criteria take into account wetlands treatment and habitat creation for optimal waterfowl use.

One of the initial considerations in the "polishing" of treatment water is retention time. For the following reasons wetlands should be designed to optimize retention time.

- To avoid surface discharge.
- To maximize treatment efficiency during cold months when plant uptake is minimal.

If retention time is not controlled effectively, still ponds can result. Still ponds should be avoided for the following reasons.

- Lower oxygenation results, which reduces plant growth.
- The potential development of avian botulism increases.
- Freezing occurs more readily than in moving water.

The vegetation-water interface is another important consideration in the design of wetlands. An approximate surface ratio of 1:2 (water to wetlands) will provide quality waterfowl habitat. Water depth needs to be controlled: the optimum depth is 18 inches for emergent vegetation production, and more than 3 feet will drown out most desirable species. Flow control structures will regulate effluent supply and can be used to drain the marsh if the need arises (e.g., botulism outbreak).

In order to encourage high wildlife productivity and density, heterogeneity of vegetation is desirable. Heterogeneity is directly related to the following factors.

- Number of vegetation communities.

- Number of vegetation layers.

- Interspersion of wetlands, upland, and open water.

Diverse vegetation communities are best maintained at low concentrations of major constituents, but even at TDS values of 6,500 ppm, desirable marsh species can be maintained. To have optimal wetlands production, vegetation communities that should be managed for include the following.

- Open water with floating plants (e.g., duckweed).

- Emergent wetlands (bulrush, tule, cattail) for cover.

- Wet meadows (rushes, sedges, wetlands grasses) for nesting.

- Riparian phreatophytes (willow, cottonwood, horticultural shrubs) provide wildlife habitat along canal systems.

- Upland shrubs and grasses for forage.

Wetlands are constantly changing dynamic ecosystems and respond rapidly to environmental perturbations. If carefully designed, the wetlands will need only minimum maintenance to keep the relative amount of vegetation types constant. When carefully designed, any necessary maintenance also would be limited to draining wetlands, allowing them to dry out, and perhaps burning standing dead vegetation.

A program that periodically assesses vegetation development and wildlife use could be used to optimize wetlands maintenance.

Marsh Construction and Maintenance Costs

Non-site-specific, order-of-magnitude cost estimates were developed for comparison of wetlands development with alternative spent geothermal effluent disposal methods. Costs were developed based on other marsh development projects and conceptual layouts of systems for assumed site conditions. A 20% contingency and an 18% overhead, engineering, and administration allowance were added to the construction cost estimates.

Factors affecting costs include the quantity and quality of effluent, application rates, land area requirement, geographic location, land use, effluent requirements, and system design. The quantity of flow depends on how the geothermal resource is used. For space heating, one residence may use about 10 gpm. A small heating district of several homes may use 300 gpm. A large hospital would use between 200 and 500 gpm. Spent fluid from these uses would have a temperature generally between 30° and 50° C.

Single industrial plants would probably use about 300 to 400 gpm of geothermal water. A large industrial plant may use up to 1,000 gpm. Flow quantity varies greatly, depending on the particular use. Spent fluid from an industrial use would range between approximately 50° and 75° C.

A 25-megawatt power generation facility would use approximately 30,000 gpm. The effluent from this use would have a temperature of about 100° C, depending on the heat source and heat exchange process in use.

Literature was reviewed to determine probable effluent application rates; that is, how much land would be required per unit of effluent. From studies conducted in Utah (Jensen 1974), it was estimated that the minimum water requirement to maintain a wetlands would be about 4.5 gpm/ acre. Research done in Michigan (Small 1976) indicates that the upper hydraulic design limit would be about 70 gpm/ac for a marsh and 35 gpm/ac for a combination marsh/pond system.

The potential application rates obviously vary over a wide range depending on the climate, site conditions, and intended operation of the wetlands system.

Another factor affecting the application rate is whether or not discharge from the wetlands is allowed. Information developed in Section 4 indicates that no discharge may be allowed in certain instances. Where no discharge is allowed, the wetlands system must utilize all of the effluent by a combination of evapotranspiration and percolation (assuming cleansing) to the ground water system. The cost estimates developed herein assume that the application rate where no discharge is allowed would be 10 gpm/ acre. Where discharge is allowed, the assumed application rate would be 50 gpm/ac.

The land area required will vary from 2 acres (100 gpm applied at 50 gpm/ac) to about 3,000 acres (30,000 gpm at 10 gpm/ac). In all instances, additional land will be required for access roads, operation buildings, and buffer areas. This may range from 300% to the net area for very small systems to about 5% additional area for large systems. The cost of land was included in the cost estimates. An assumed average value of $1,000 per acre was used. Site-specific analysis would be required to refine this estimate. The land cost may range from zero dollars per acre for existing publicly owned wetlands up to several thousands of dollars per acre for existing open space that would be converted to wetlands.

The design of wetlands systems will vary greatly, depending on site conditions and the required level of treatment by the wetlands. As a minimum, the system may consist of a simple diffuser pipe laid in an existing wetlands and a few baffle dikes to prevent short-circuiting of the effluent flow to the marsh discharge point. This type of system would be applicable where a relatively small amount of effluent would be discharged into a very large existing marsh. Minor diking and water control structures could be included in backwater and floodplain areas, which would enlarge and/or enhance the existing wetlands.

As the effluent flow becomes a larger proportion of the total wetlands water source, greater amounts of effluent control facilities will be required. In an area where a wetland is created (that is, where no wetland existed before) the entire area might require diking and structures to provide for the water level control crucial to management of waterfowl populations.

Evaporation from free water surfaces, in the seven study area States, ranges from 20 to 82 inches per year. About 75% of the evaporation (15 to 60 inches) occurs during the warmer months of May through October. These evaporation rates equal 1 to 5 gpm/ac on a year-long basis and about 2 to 6 gpm/ac during the summer. In comparing these values with the influent application rate of 10 to 50 gpm/ac, it can be seen that 2 to 60% or more of the geothermal influent may evaporate. Salts will be concentrated by evaporation, causing a buildup of salts in the wetlands. This problem will be especially acute where discharge from the wetlands is not permitted. A detailed, site-specific salt balance analysis will be required, especially where discharge is not permitted and where the influent is high in salts. Without the site-specific analysis it cannot be determined which sites would be made infeasible for wetlands use of geothermal effluents.

However, it can be assumed that this could generally be less feasible where salts are high in the water and where discharge is not permitted.

Other factors that may significantly increase the construction costs include the need to divert other waters from existing wetlands, flood protection facilities, and specific features for wildlife enhancement. Costs for these items were not included in the estimates used for comparison evaluations.

Costs were developed for operation and maintenance. The operating costs assume that the system would be managed on a regular basis to control water levels. An allowance was also included for monitoring, dike and water control structure maintenance, and energy for pumping water within the wetlands area.

Figures 4 and 5 present the capital costs and operation and maintenance costs, respectively. Capital costs are presented both for enhancing existing wetlands and for creating new wetlands. Costs were also differentiated by whether or not discharge was allowed from the wetlands.

Also plotted are the costs for three systems that are probably near the high and low ends of the cost range for wetlands enhancement systems. The Incline Village General Improvement District (IVGID) project (CH2M HILL 1979) is expected to cost about $5.6 million for disposal of about 1,500 gpm of sewage effluent on 700 acres total area. For this project, the assessed land cost was $2,000 per acre, the system could allow no discharge of the effluent, springs on the existing wetlands had to be diverted off of the site, and extensive diking and storage for floodwaters had to be included. This project both enhances existing wetlands and creates new ones. These factors all tend to increase the cost of a wetlands enhancement system, placing this facility at the high end of the range for wetlands systems.

At the low end of the range is the Mountain View Sanitation District system at Martinez, California (Demgen and Nute 1979). Here, a much smaller volume (800 gpm) of effluent is discharged onto a previously owned parcel of land, and few water control structures are necessary. Discharge is allowed from this system. Also at this end of the price range is a 300-acre ($1,700/acre) wildlife enhancement project near Vancouver, B.C. This project utilizes an existing marsh (Barnes 1980).

As is apparent from Figure 4, the costs are about four times higher for a zero-discharge system compared with a system where discharge is allowed. This is predominantly because of the larger land area requirements (about five times). However, some economy of scale is apparent on the larger systems. Created wetlands will normally cost more than existing wetlands, mainly

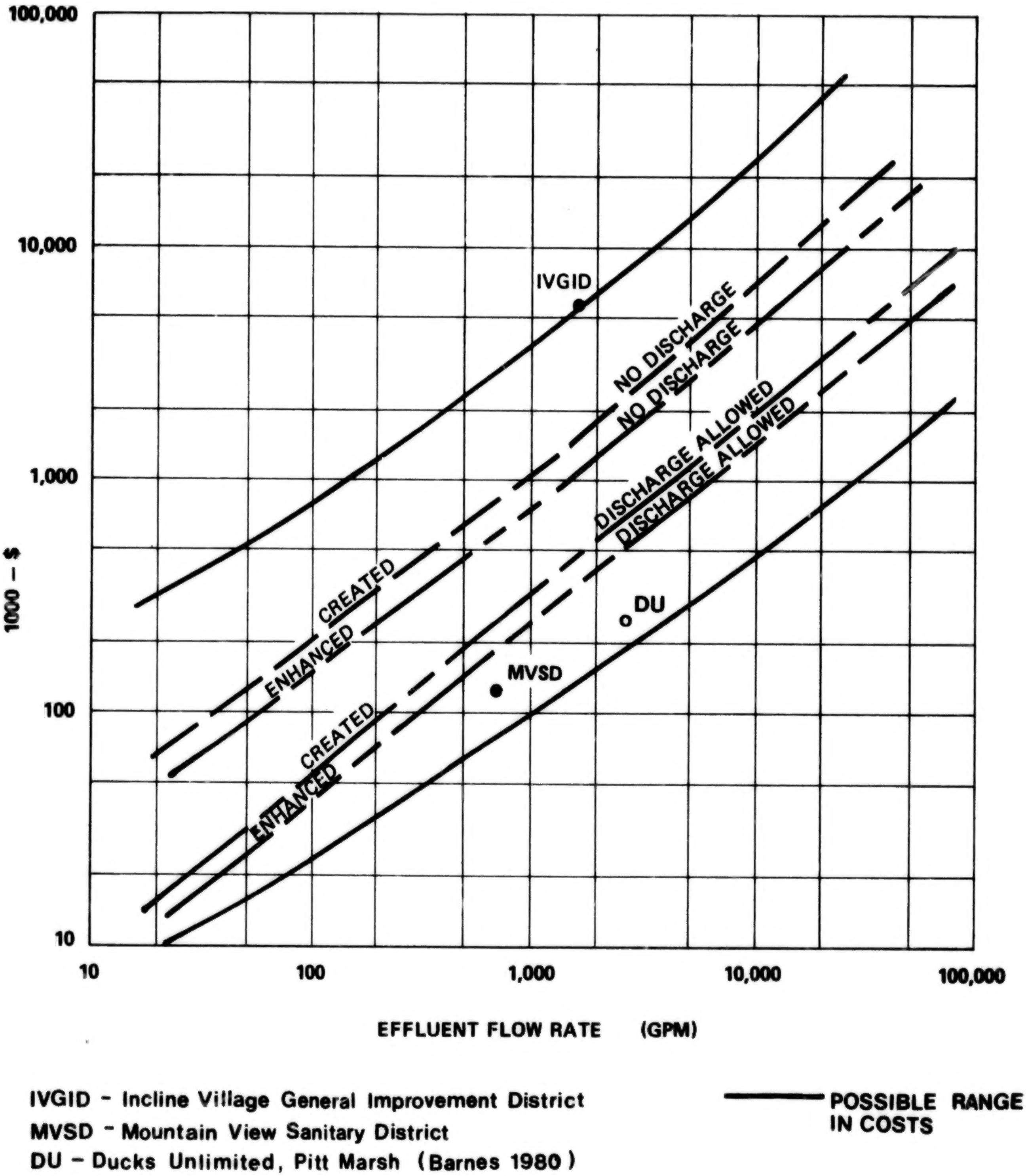

Figure 4. Wetlands construction cost.

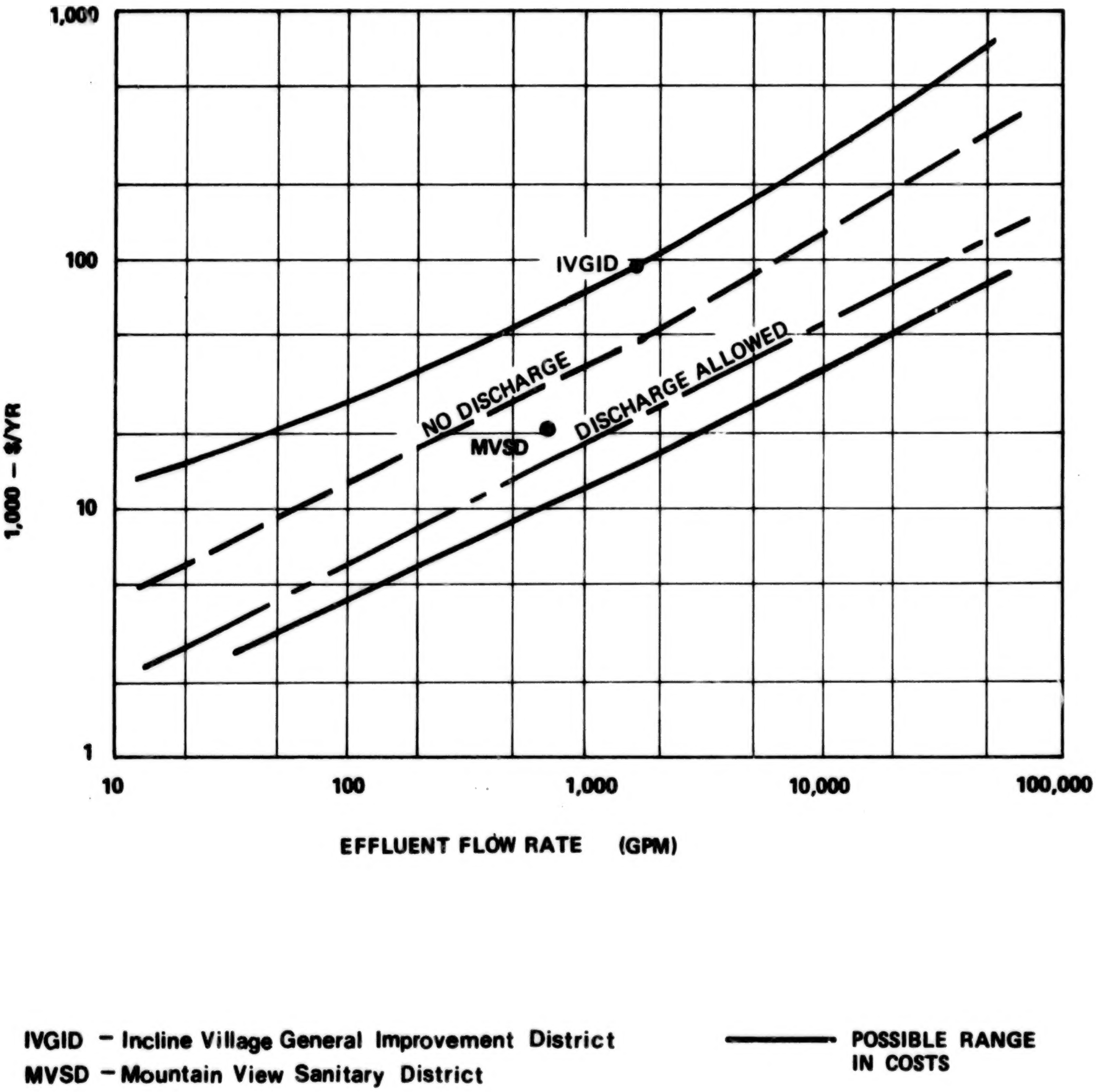

Figure 5. Wetlands operation and maintenance cost.

because of the need for more construction of dikes and water control facilities. This assumes that where existing wetlands are used, existing topography will allow the use of less diking. This also assumes that created wetlands will have to have their boundary areas controlled. If wetlands bounds are not a concern, diking costs will be substantially less but land costs could be substantially more. The cost estimates on Figure 4 must be viewed only as order-of-magnitude estimates. This information does indicate, however, that systems where discharge is allowed will be much less costly.

Operation and maintenance costs will also be greater for zero-discharge systems (Fig. 5). Again, this is because five times more land is required for a no-discharge system. Consequently, labor and maintenance costs will be considerably higher. The IVGID project cost estimate is shown as the probable maximum because of the complications of requiring diversion of existing onsite waters, flood control, and water storage. On very simple systems, where relatively small amounts of water are discharged into large marshes, operation and maintenance costs may be greatly reduced in comparison with the IVGID system.

EFFLUENT DISPOSAL BY SURFACE DISCHARGE

An often-mentioned and highly controversial disposal method would release spent geothermal waters to rivers, streams, or lakes in the vicinity of the development. Any disposal to surface waters would require review and permitting by the appropriate State and Federal agencies. This would entail meeting State and Federal water quality standards.

Geothermal effluents would be treated as a point source of pollution, which would require an NPDES permit from the Environmental Protection Agency. Only a few of the 91 geographic areas in the seven state project area would meet existing State water quality regulations without pretreatment and could potentially discharge to surface waters. All other areas would require sufficient pretreatment to bring concentrations of chemical constituents down to levels compatible with State water quality regulations. At present, this would not be cost-effective (see Pretreatment Section). Another factor for consideration would be flow rates of the nearest stream or river and low flow periods during winter months. These low flows usually correspond to peak heating demand periods and, consequently, maximum geothermal discharge rates. At such high inputs (20 to 50% of total streamflow), thermal and chemical effects of the effluent on aquatic ecosystems could be substantial although the effluent may meet water quality standards.

One method of overcoming peak flow disposal problems includes the use of holding ponds. They would require extensive acreage to hold the majority of water when river flow is low. An advantage of holding ponds would be the reduction in temperatures before effluent entered the river system.

The conveyance system from the source to the discharge point could be gravity-fed open canals or ditches. Two advantages to this type of system are evident. Open channel flow would provide evaporative cooling and could facilitate the growth of riparian vegetation along the banks. Riparian vegetation would enhance wildlife use of the area.

Costs

Cost is the major advantage to surface stream disposal of geothermal effluent, if no pretreatment is required. A pumping station and canal would be relatively inexpensive. If a gravity flow system is used, the pumping station costs could be eliminated.

The cost of constructing and operating conveyance systems will vary with the route, construction methods, flow rate, and need for pumping. A very rough estimate for open canal construction (common trapezoidal structure dug with a backhoe or similar device) would be $2.00 a cubic yard. Compaction of dirt along banks can run $2.00 to $3.00 more a cubic yard. If concrete lining is desired, additional costs of $1.75 a square foot are encountered. Using a 38% contingency and overhead and easement costs, order-of-magnitude costs were developed for unlined canals that could vary between $60,000 and $800,000 per mile. It is recommended that for 100 gpm of flow the maximum distance from source to discharge point be approximately 2 miles, for 10,000 gpm approximately 6 miles, and for 30,000 gpm approximately 12 miles. These recommendations are based on holding conveyance systems cost to a minimum.

Pumping systems are usually designed for a velocity of 4 feet/second (fps). An order-of-magnitude estimate for pumping facilities is $15,000 for 100 gpm capacity. The annual cost for power and maintenance could be reduced if cogeneration were used to power any pumping stations required. In reality, costs are site-specific and a detailed analysis cannot be provided.

The use of surface stream discharge depends on the quality and quantity of effluent, proximity to rivers or streams of sufficient size and flow, and accessibility of State and Federal permits.

EFFLUENT DISPOSAL BY SUBSURFACE INJECTION

At present, the only alternative to treatment and release of geothermal effluents that does not meet water quality criteria is subsurface injection. Injection wells are normally drilled in a manner similar to that used for drilling a production well. The hole is cased and perforated in the zones where injected water is to be dispersed. Depending on the relative dispersion depth, injection wells are classed as either shallow or deep.

Deep wells are necessarily more expensive than shallow wells. However, dispersing the geothermal water at greater depths reduces the possibility of interference with shallow aquifers. In shallow injection, contamination of domestic wells may result from increased temperatures and/or trace chemicals such as fluoride.

The injection well could be located either near the source geothermal wells or near the project site, if they are not the same. Locating the injecting well near the end user may eliminate the need for long transmission mains back to the injection well. Injection wells located near the source wells have the advantage of putting the spent geothermal fluid back into approximately the same aquifer, replenishing the supply. This may also reduce the potential for ground subsidence caused by withdrawal from the source wells.

A possible disadvantage with injecting near the source wells is short-circuiting within the aquifer, resulting in lower temperatures being produced from the source wells. Actual temperature reduction in the source wells would be a function of many parameters, including extent of the resource and/or direction of flow of the resource, and rock formation characteristics.

Ground water contamination could also occur, depending on the interaction between the geothermal and shallow ground water aquifers in the area. Even with geologic investigations before development, monitoring will be required to ensure that this does not occur. Injection wells must meet the requirements of EPA's Underground Injection Control Program regulations that specify review, construction, and monitoring requirements.

Injection without treatment is a popular disposal technique, particularly with low-quality effluent. Treatment may be necessary, however, just as in oil-field operations. The plugging of disposal wells and surrounding subsurface formations may need to be controlled through fluid treatment. Common causes are silica precipitation, calcite precipitation, collection of suspended solids, and alteration of formation minerals due to chemical incompatibility. Where scaling and plugging are a problem, they add to the overall costs of injection.

The cost of constructing and operating wells for injection disposal of spent geothermal effluents will vary greatly with site conditions and flow rates. Injection costs are a function of well depth, diameter, drilling requirements, and type of well development required. The size of the well bore is determined by the amount of fluid to be injected and the permeability of the receiving formation. Cost estimates for geothermal injection wells are currently (1980) $15 per foot per casing diameter inch. These costs are based on CH2M HILL's experience and are valid to a depth of about 3,000 feet. Where deeper injection is required, the costs begin to rise rapidly. This is because larger drill rigs, similar to those used in the petroleum industry, are needed. Costs also may approach $30 per foot per diameter inch in difficult drilling circumstances.

Other costs associated with injection are related to pumps and controls. Typical injection pump stations are surface installations utilizing horizontal split case, centrifugal, or canned turbine pumps. Pump size and type are determined by the amount of water injected and by the injection head required. The injection head (or pressure) is largely determined by the receiving formation permeability and whether injected fluid is readily accepted or must be high-pressure injected. Injection pump station costs can vary significantly, depending on pump type, flow rates, and head requirements.

A common size for injection wells is a 12- to 14-inch borehole with 10-inch casing grouted in place. Assuming $15 per foot per casing diameter inch, a typical injection well will cost about $150 per foot to drill and case. The depth of injection is totally site-specific.

For comparison purposes, assume a typical depth of 3,000 feet. This yields a cost of about $500,000 per well. Pumps and injection tubing may add another $100,000 to this typical well example. The total cost for a well, which may inject anywhere from several hundred to several thousand gallons per minute, would be approximately $600,000. With 38% contingencies and overheads, the cost estimate is about $830,000. Two or more wells may be required where one well cannot provide enough capacity. In addition, operating and maintenance costs would be several thousand dollars annually, mainly for power and pump maintenance.

Wells may not have to be drilled specifically for injection in areas developed for electrical energy production if unusable production wells are available to serve this purpose. Costs of disposal in this instance would be mainly for transmission pipes, pretreatment if necessary, and pump station requirements.

COMPARISON OF DISPOSAL METHODS

Perhaps the easiest means of comparing effluent disposal methods is graphically. Table 23 discusses the advantages and disadvantages of each method as well as the feasibility. Table 24 compares costs associated with each disposal method. As is evident in Table 24, wetlands and injection have approximately the same order-of-magnitude costs. Surface discharge would be the most desirable economically, until high technology pretreatment costs are included. Detailed, site-specific investigations would be required to choose the most economically feasible method of disposal.

Table 23. Effluent disposal alternatives.

Disposal	Description	Advantages:Disadvantages	Status
Wetlands creation-enhancement	Discharge geothermal effluent to existing marshes to icrease area or waterfowl use time; create new wetlands in arid areas on suitable sites.	Create or prolong waterfowl and wildlife habitat in areas currently lacking it; potential for cascading uses of effluent either before or after land application; "polishing" effect of marsh on geothermal aquifer life; after life of project, wetlands cease to exist; only demonstrated with sewage and industrial application--initial establishment may take time.	Feasible
Surface dishcarge	Discharge geothermal effluent to rivers, streams, or lakes through channel system.	Could promote establishment of riparian vegetation along canal banks; prolong stream life; could have detrimental effects on river and lake ecosystems; extensive pretreatment necessary in most cases would be cost prohibitive.	Pretreatment costs too high for economic feasibility.
Injection	Inject effluent back to geothermal aquifer under high pressure.	Flow not restricted; may prevent subsidence; pretreatment may be necessary in some cases; may prolong life of geothermal aquifer; potential for drinking water aquifer contamination.	Current method used for disposal.

Table 24. Cost comparison of disposal and pretreatment methods.

	Disposal			Pretreatment		
Flow (gpm)	Wetlands ($/1,000 gal)	Surface Discharge Conveyance system per mile ($1/,000 gal)	Reinjection ($/1,000 gal)	Cooling ($1,000 gal)	Low tech. ($1,000 gal)	High tech. ($1,000 gal)
100	0.21-0.71	0.16	0.70	0.05-0.40	0.60-1.50	0.78-2.19
1,500	0.09-0.24	0.034	0.14	0.016-0.044	0.02-0.40	0.31-1.79
30,000	0.035-0.16	0.007	0.10	0.01-0.03	0.01-0.40	0.20-1.28

FEDERAL AGENCY REQUIREMENTS

The Federal government owns a large portion of the total land area of the seven subject States (e.g., about 52% of Oregon). These lands are primarily under U.S. Forest Service (USFS) and U.S. Bureau of Land Management (BLM) control. Many of the known and potential geothermal resources lie within the Federal domain. Federal agencies and permits affecting geothermal development and utilization are listed in Table 25. An Interagency Geothermal Coordinating Council (IGCC), sponsored by the U.S. Department of Energy (DOE), has been established to achieve institutional consistency and effectiveness. The Federal agencies most involved with geothermal resources include U.S. Geological Survey (USGS), DOE, BLM, and USFS.

Substantial development of geothermal resources on Federal lands can occur only if the lands are readily available for exploration and development. Systematic exploration and development are sometimes inhibited because, in some instances, Federal management agencies lease only selected portions of geologically promising areas because of competing interests (e.g., fish and wildlife resources, recreation). Private companies have been reluctant to risk major investments unless they control contiguous parcels. Developers who do not control a contiguous lease face the unattractive prospect of competitive and more costly leasing for adjacent Federal lands. Private developers generally are reluctant to make financial commitments for deep drilling without firm and substantial lease positions.

The Federal leasing process to date is very slow. Many public and private groups have been awaiting leasing decisions since the early 1970's. This situation has, to some extent, inhibited geothermal development.

The Federal agencies that have responsibilities to administer geothermal developments have varying roles in each of the States, depending on the State process. The four Federal agencies with major responsibilities in geothermal development in the project States are listed below.

Department of Energy

Although the DOE does not actively regulate geothermal development, it is charged with developing and demonstrating the commercial viability of geothermal energy conversion. This objective is accomplished in concert with private developers through grants, contracts, and loan guarantees. All programs funded through the DOE must meet environmental standards, with particular emphasis on protection of the environment and safety.

Table 25. Federal agency permit requirements.

Federal agencies	Permit	Required before	Estimated time for issuance	Notes
U.S. Bureau of Land Management	Permit for pre-lease operation	Nonsurface-disturbing exploratory activities on lands not leased by applicant	30 days	Includes geophysical/geological exploration, temperature gradient surveys, etc., 30-day time limit for approval
	Issue lease-BLM lands			
	Conduct EAR		About 5 months	
	Conduct KGRA lease sales			
	Issue lease		Total: about 8 months	
	Plant Siting Permit	Plant construction	Not known	
	Post-lease joint approval with USGS of plans or operations			Site-specific
U.S. Forest Service	Special use permit for pre-lease operation	Before exploratory activities on lands not leased by applicant	30 days	Includes geophysical/geological exploration, temperature gradient surveys, etc., 30-day time limit for approval
	Issue lease-Forest Service lands	Before major exploratory activities	About 17 months or longer	Lease obtains rights to the resource
	Conduct EAR KGRA land sales; approve lease			
	Joint approval with USGS of plans of operation			
U.S. Geological Survey	Administer terms of lease			
	Approve permit for exploratory activities	Before nonsurface-disturbing activities	30 days	Includes geophysical/geological activities, temperature gradient surveys, etc., 30-day time limit for approval
	Conduct site-specific environmental analysis and approval of plans of operation			
	Exploration	Before nonsurface-disturbing activities	About 1 year	
	Environmental baseline data	Gathering of required 1 year's environmental baseline data	About 3 to 5 months	Must be completed at least 1 year before plan of production is submitted
	Development	Drilling and development of production wells	About 3 to 5 months	Define extent of field
	Injection	Drilling and development of injection system	About 3 to 5 months	

Table 25. (concluded)

Federal agencies	Permit	Required before	Estimated time for issuance	Notes
	Utilization	Construction of power plant	About 3 to 5 months	Sundry notices submitted for each phase; includes contract and royalty breakdown
	Production	Use of the resource for power production	About 3 to 5 months	Includes production data from wells and target date for completion
	Changes in plans of operation	Before implementation of changes in plans of operation	A few months	Sundry notices
U.S. Environmental Protection Agency	Certify air discharge permit		About 90 days	
	Issue water permit		About 90 days	Air, water, solid waste permits are in conjunction with state environmental health agencies
	Issue solid waste disposal permit		About 90 days	
	Review of EIS			

Bureau of Land Management

The BLM, in the U.S. Department of the Interior, has jurisdiction over mineral and related subsurface resources on public lands. The BLM role includes the following activities.

- Receiving and processing lease applications for noncompetitive leases.
- Publishing lease sale notices.
- Awarding leases.
- Establishing lease conditions.
- Administering leases (except those functions assigned to the USGS or USFS).

U.S. Geological Survey

The Conservation Division of the USGS has expertise in geothermal geology and engineering. Its role includes the following activities.

- Supervising activity inside the area of operation on leased lands (Area Geothermal Supervisor provides post-lease management on Federal lands).
- Preparing post-leased environmental studies on development proposals (USFS provides input on surface management environmental considerations).
- Providing input on geothermal geology and hydrology resource assessment (USFS has primary responsibility on National Forest land for pre-lease NEPA assessments).
- Approval of the plan of operations.
- Issuing geothermal resource operation orders.
- Consulting on litigation or control situations peculiar to specific lease areas.

U.S. Forest Service

As the surface management agency, the USFS is responsible for the following activities.

- Preparation of pre-lease Environmental Assessments or Environmental Statements on the suitability of National Forest lands for geothermal leasing purposes (USGS provides input).

- Input to USGS on surface management environmental considerations for use in preparation of post-lease Environmental Assessments on specific development proposals (USGS has primary responsibility).

- Preparation of lease controls and site-specific stipulations.

- Co-approval of the plan of operations.

- Issuance of special use permits for the use of lands needed for development purposes when not appropriate in the plan of operations phase. Such facilities as roads, powerline transmission lines, and generating plants not covered by the original lease could be covered by such a special use permit.

- Management of leased lands beyond area of operation.

Supporting Legislation

The Geothermal Steam Act of 1970 (Public Law 91-581) authorized the Secretary of the Interior to issue leases for the development of geothermal resources. Lands available for leasing include the following categories.

- Public, withdrawn, and acquired lands administered by the Secretary of the Interior.

- National Forest and other lands administered by the U.S. Department of Agriculture through the USFS.

- Lands that have been conveyed by the United States subject to reservation of the geothermal steam and associated geothermal resources therein.

Lands excluded from leasing include national recreation areas, lands in a fish hatchery administered by the Secretary of the Interior, wildlife refuges, game refuges, wildlife management areas, waterfowl, and protection and conservation of fish and wildlife that are threatened with extinction, and tribally or individually owned Indian trust or restricted lands, within or outside the boundaries of the Indian reservations.

Although it excludes leases in wildlife management areas, the Geothermal Steam Act of 1970 does not appear to restrict the development of new wetlands or wildlife areas.

All geothermal energy development is subject to many pollution control laws and regulations. The most significant of the Federal laws are the following which apply to all industrial development.

- The Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500). The implementation of effluent guidelines and water quality standards is carried out under authority of Section 402 of the FWPCA by way of the National Pollutant Discharge Elimination System (NPDES). This act requires a discharge permit based on effluent guidelines and/or water quality standards for any point source discharge to surface drainage (wetlands). Permitting authority has been delegated to those States that have met implementation program requirements. Oregon, Nevada, California, and Montana have been delegated this authority. In Nevada and Montana, EPA has retained this authority for Federal lands. The EPA issues permits in Idaho, Utah, and New Mexico.

- The Clean Air Act as amended (P.L. 92-604 and P.L. 95-95). National air quality standards have been established for six pollutants thus far: particulates, sulfur dioxide, nitrogen oxides, hydrocarbons, photochemical oxidants, and carbon monoxide. These pollutants may not be significant in most geothermal sources, and the importance of current ambient standards may not be great. However, the States may unilaterally include other constituents, and some have done so (e.g., hydrogen sulfide in California). The Clean Air Act amendments of 1977 also provide for the regulation of emissions of radioactive substances, cadmium, and arsenic, all of which may be found in geothermal fluids. They require the application of best available control technology in standards attainment areas, such as many areas of geothermal development, to "prevent significant deterioration" of air quality.

- The Safe Drinking Water Act (P.L. 93-523). This act is administered by EPA. Its greatest significance to geothermal energy development is that it requires the promulgation of regulations to control underground injection. Regulations under this act have been promulgated that specify minimum review, construction, and monitoring requirements. Although this act does not directly relate to wetlands development, it does apply to a possible alternative disposal method.

- The Resource Conservation and Recovery Act of 1976 (P.L. 94-580). The provisions of this act, administered by EPA, are principally concerned with solid wastes. Geothermal wastes are specifically excluded from the hazardous waste classification, at least until a study of their nature and management methods has been completed (10/82). Later regulations, if the wastes are found to be hazardous, may have significant ramifications for geothermal development in those circumstances where spent brine or effluent surface impoundments are used and where waste sludges are created.

- Section 318 of the Federal Water Pollution Control Act (FWPCA) authorizes the Administrator, after public hearing, to permit the discharge of a specific pollutant or pollutants associated with an approved aquaculture project under controlled conditions and under Federal or State supervision. Such authorization would be permitted through the NPDES process and would be subject to conditions determined necessary by the Administrator to carry out the provisions of the FWPCA.

All of the above Federal laws allow and foster delegation of authority to the States upon their meeting certain requirements.

STATE REQUIREMENTS

Many of the State agencies responsible for overseeing geothermal development are relative newcomers to regulating geothermal development, use, and disposal. Several States have few formal regulations specific to geothermal development, and regulation of the resource has not yet been significantly institutionalized. This can be an asset because of minimal bureaucratic involvement, but is also a constraint because absolute procedures and requirements for geothermal development, use, and disposal are not always clearly defined.

In general, legal and institutional constraints do not appear insurmountable for wetlands development. The constraints vary not only from State to State, but can also vary from site to site within each State. Actual development of a wetlands is highly site-specific and generally requires a determination that this form of disposal is preferable over other available options, such as injection.

In areas where subsidence has occurred in the past, such as in certain California counties, injection may be the only disposal option permitted. No States require complete injection of the spent geothermal waters. California has the most stringent regulations for injection and generally requires that up to 80% of the extracted water be injected. Counties have the option of applying even more stringent requirements, and Imperial County in California requires 100% injection.

The other States, however, allow disposal by other means if adequate evaluation and provisions for controlling potential environmental problems (subsidence, air and water pollution) are made. Oregon policies generally require injection; however, if public benefit can be demonstrated by an alternative disposal method, the alternative may be permitted.

The other primary potential constraint to wetlands disposal may be water rights appropriations. The geothermal resource is considered a mineral resource, a water resource, both and, in some cases, a separate entity, depending on the State. In many situations, this determination is not clearly defined, and will be resolved only through legal interpretations. Assuming that the required water rights appropriations have been obtained for actual development and industrial use of the resource, the question of water rights for the spent fluid remains. Priorities for water rights appropriations, and requirements for documentation that water rights of previous users would not be affected, may pose limitations to wetlands disposal in specific instances. The question of water rights is a complex legal issue, and legal opinions on the ultimate disposal of the resource may be necessary before proceeding with any specific wetlands enhancement project.

General requirements for geothermal development and disposal are outlined in the following section. Because regulation of geothermal development, use, and disposal is in early stages in several of the States, it is anticipated that regulations will continue to evolve for all aspects of development. For instance, Oregon is in the process of developing regulations for disposal of the resource, and it is not clear how the finally adopted regulations will affect the potential for surface disposal of the spent fluid. As the resource continues to be developed, additional regulations promulgated at the State and local levels could provide encouragement or added constraints for alternative uses of the resource.

Idaho

Geothermal resource development in Idaho is controlled by three legislative acts. The statutory authority for the disposition of geothermal resources that underlie acquired lands, mineral reserved lands, and public domain lands is the Geothermal Steam Act of 1970. Idaho, under the statutory authority of the Idaho Geothermal Resources Act of 1972, has also declared its interest by claiming the right to regulate the development and use of all geothermal resources on all lands within the State. The State Board of Land Commissioners issues leases for geothermal development on State lands.

The Idaho Water Law requires the water resources of the State be devoted to beneficial use in reasonable amounts through appropriation.

The Idaho Geothermal Resources Act of 1972 gives regulating authority for all geothermal development to the Idaho Department of Water Resources. Drilling permits must be filed with the State to ensure proper resource production and reservoir maintenance, environmental regulation, and constant monitoring of geothermal resources. No waste disposal or injection well can be constructed without a permit from the Department of Water Resources. Idaho classifies geothermal resources as neither water nor mineral resources, but closely related to both. To control possible conflicts between geothermal utilization and State water appropriation, the regulatory power of the State's Geothermal Resource Act was placed with the Idaho Department of Water Resources.

The potential for discord between geothermal development and water resources is considered a critical legal conflict in Idaho. The other legal issue that is yet to be decided is actual ownership of the resource. The implication of the Idaho Geothermal Resource Act of 1972 is that low-temperature geothermal utilization requires only a valid water right permit and such operations would be regulated by the appropriation laws of the State. Higher temperature utilization for energy use or mineral resource, requires a geothermal resource permit, but does not require a water right permit. The distinction between high and low temperature use is around 300° F; however, this distinction is more related to potential end use (power plant as opposed to space heating) than to actual reservoir temperatures.

Cities are now authorized to issue revenue bonds to finance construction costs of geothermal and associated systems. Counties are authorized to operate similar systems, but they cannot issue revenue bonds.

The Idaho Geothermal Resources Act of 1972 specifically exempts some geothermal development from permitting requirements. The Act states:

> ...no person operating or proposing to operate a geothermal heated greenhouse, hot house, swimming pool, hot springs bath, or hot water fish propagation facility, space heating plant or similar facility, unless such

operation is in conjunction with the geothermal resource use not specified in this subdivision, shall be compelled to comply with the geothermal resource permit requirements under this act if such person obtains a valid water right permit for such operation.

Drilling and development of low-temperature wells for any of the above geothermal operations would be regulated by the ground water appropriation laws and water well drilling regulations of the State.

Table 26 shows agency permit requirements for development of geothermal resource use in Idaho.

Montana

The Alternative Energy Division of the Montana Department of Natural Resources and Conservation published a "Montana Handbook for Geothermal Development" in April 1980. This handbook discusses the various statutes and regulations pertaining to geothermal development in Montana.

In Montana, geothermal resources can be treated either as water or minerals. The water-mineral question is important, primarily in situations where the surface rights to land have been severed from the mineral rights. If geothermal resources are treated as water, they belong to the surface owner. If mineral, they belong to the subsurface estate.

Both State and Federal laws have made it clear that mineral reservations on State and Federal land do include geothermal resources. On private lands, the State's water laws will apply to all geothermal developments involving production and diversion of geothermal fluids.

The State Board of Land Commissioners is authorized to grant leases on State-owned land for protection, exploration, well construction, and production of geothermal resources. Regulations adopted to implement the law are administered by the Department of State Lands. A person wishing to develop geothermal resources administered by the Board of Land Commissioners must file an application with the Division of State Land, describing the area for which he is applying. The land commissioner announces a public lease sale when sufficient applications are received for a given tract, or at the commissioner's discretion.

The law limits the terms of leases to 10 years, or for so long thereafter as geothermal resources in sufficient quantities are produced. The lease must provide for a royalty of at least 10% of the gross revenue from the sale of heat energy, steam brine, and associated gases. The lease also includes a royalty of not less than 2% or more than 5% of gross revenues from the sale of byproducts recovered from geothermal fluids, including operation of springs for health or recreational purposes.

Table 26. Agency and permit requirements in Idaho.

Agency	Permit responsibility	Processing time
County and local government	Issue land use and construction permits	Variable; generally 1-3 months
State government		
Department of Water Resources	Issue drilling and exploration permits	1-3 years for State permit approvals
Idaho Department of Health Welfare	Water right permit Construction bonds ($10,000) Issue production permit	
Public Utilities Commission	Issue utility charter	

Regulations set minimum requirements for casings, abandonment procedures, and waste disposal. The regulations call for reclamation of surface land disturbed by exploration and development, and a plan of operations that describes environmental protection measures and other features. The lease constraints allow for joint development of geothermal resources, subject to approval by the Board. The Board may also enter into pooling agreements on behalf of the State of Montana.

Geothermal developments are subject to water appropriation procedures of the Water Use Act. Any geothermal well and associated facilities will require a water use permit and will be subject to the rights of prior water users. The development of wetlands would probably require the acquisition of water rights. Application would have to be made to the State Land Board for permission to secure such rights. If permission is granted, the applicant must file an application in the name of the State of Montana in accordance with the Water Use Act.

Geothermal developments are also subject to the requirement of the Major Facility Siting Act. The Major Facility Siting Act provides for the comprehensive review of the siting and construction of major facilities engaged in generation, distribution, and conversion of energy. The Act is administered by the Energy Planning Division of the Department of Natural Resources and Conservation. The Board of Natural Resources and Conservation provides policy direction.

All exploratory activity must be reported to the Department of Natural Resources and Conservation. In some cases, the Board of Natural Resources and Conservation must issue certificate of public need and environmental compatibility, which follows extensive environmental studies and public hearings, before development may commence.

Under the Montana Water Pollution Control Act, injection of geothermal effluent is subject to permit requirements of the Department of Health and Environmental Sciences. Pollution control regulations may also be applicable to control hydrogen sulfide or other emissions.

Approval of any geothermal activity, including establishment of wetlands, will require review and approval by the Departments of State Lands, Natural Resources and Conservation, and Health and Environmental Sciences. These agencies may require preparation of environmental impact statements and/or applications for certificates of environmental compatibility and public need pursuant to the Montana Environmental Policy Act. Up to 2 years may be required for these studies.

Studies and consultations are also conducted for and with the Departments of Health and Environmental Sciences, Fish and Game, Highways, and Public Service Regulation. All facilities must be certified by the DNRC Board and the Department of Health as being in compliance with Air and Water Quality Standards and implementation plans. Table 27 includes the steps that must be taken for approval and the agencies that have jurisdiction.

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Table 27. Agency and permit requirements in Montana.

ncy	Permit	Required before	Time for issuance	Fed-eral	State	Lo-cal	Pri-vate	Comments
S	Incorporation	Doing business in state	Approximately 1 month	X	X	X	X	
L	Geothermal lease	Casual exploration	Indefinite		X			Competitive bids; BLC land only
er state encies	Geothermal lease	Casual exploration	1-3 months		X			Negotiate lease with appropriate agency
B	Geothermal lease	Casual exploration	1-3 months			X		Negotiate lease with appropriate agency
L	Plan of operations	Exploration			X			
nty clerk d recorder	Permit for geophysical exploration	Seismic exploration	Automatic after SOS certifies bond	X	X	X	X	File bond with SOS; give prior notice to landowner; file report with county within 30 days after tests; plug hole within 120 days after test
RC (WRD)	Interim water use permit	Test drilling	2-4 months	X	X	X	X	File well log within 60 days after hole completion
RC (FSD)	Long-range plan and exploration reports	Test drilling	Automatic	X	X	X	X	File reports before, during and after exploration relating to future "major facility"
B	Land-use permit	Land use activity					X	Where zoning ordinance apply
B or DNRC	Floodway management permit	Land use activity	Up to 60 days			X	X	In designated floodways and flood plains
B or DNR	Land use permit	Alteration of lake or shore	Up to 90 days			X	X	
CD or BCC	Land use permit	Alteration of stream or streambank	Up to 60 days			X	X	Inspection team may be requested including SWCD, DFWP and applicant
PO	Consultation	Permit issuance			X			Review of other agency permits
CD	Land use permit	Land use activity	Approximately 30 days		X	X	X	Where SWCD has adopted land-use regulations for erosion control
B	Approval	Land use activity in open space areas	Indeterminate			X	X	Where LGB holds conservation easement or other development restrictions
L	Approval	Land use activity	Indeterminate		X			In designated "natural areas"
RC (FD)	Slash disposal agreement	Tree clearing in forest areas	10 days		X	X	X	
PC (WRD)	Water use permit	Appropriation of water	Up to 180 days (240 days if EIS needed)	X	X	X	X	Secure water rights prior to development drilling

Table 27. (concluded)

Agency[a]	Permit	Required before	Time for issuance	Federal	State	Local	Private	Comments
DNRC (FSD) DHES (AQB and WQB)	Certificate of environmental compatibility and public need	Construction of "major facility"	Up to 33 months	X	X	X	X	Application preceded by at least two filings of "long-range plans" and by one year of baseline data
DSL	Easements	Construction of pipelines, transmission lines across publicly owned land	45 days		X			
DNRC					X			On state forest lands
DFWP					X			On state game refuges, parks, etc.
LGB						X		
LGB	Approval	Erection of poles; use of streets and roads for lines				X		
DH	Approval	Use of highway right-of-way for utility lines			X			On Federal-aid highway routes
DHES (AQB)	Air pollutant discharge permit	Construction of operation of air pollutant source	60 days (180 if EIS needed)	X	X	X	X	Review may be coordinated with major facility review
DHES (WQB)	Water pollutant discharge permit	Operation of water pollutant discharge point-source	180 days	X	X	X	X	Review may be coordinated with major facility review
PSC	Tariff approval	Sale of heat or electricity to public	Up to 9 months	X	X	X	X	Does not apply to cooperatives or owners' associations

[a] Agency Abbreviations

SOS	Montana Secretary of State
BIA	Bureau of Indian Affairs
DSL	Montana Department of State Lands
LGB	Local Governing Body (city or county)
DNRC	Montana Department of Natural Resources and Conservation
WRD	Water Resources Division
FSD	Facility Siting Division
FD	Forestry Division
SWCD	Soil and Water Conservation District
UCC	Board of County Commissioners
SHPO	State Historic Preservation Officer (Montana Historic Society)
DHES	Montana Department of Health and Environmental Sciences
AQB	Air Quality Bureau
WQB	Water Quality Bureau
DFWP	Montana Department of Fish, Wildlife and Parks
DH	Montana Department of Highways
PSC	Montana Public Service Commission
DR	Montana Department of Revenue (Property Tax Division)

Nevada

There are few formal regulations for geothermal development in Nevada. The Nevada Department of Conservation and Natural Resources is responsible for regulating geothermal development through several divisions: Water Resources, State Lands, Environmental Protection, Water Planning, and Minerals.

The Division of Water Resources licenses geothermal drillers, issues drilling permits, and issues permits authorizing appropriation of geothermal resources. The Division of State Lands issues leases, but very little of Nevada land is State-owned. The Division of Environmental Protection enforces air and water quality standards. The Division of Water Planning has general planning functions that may affect geothermal development. The Division of Minerals regulates certain geothermal exploration activities.

Nevada's regulations do not appear to constitute a significant constraint to geothermal or wetlands development. There is no need to meet water quality regulations if no consumptive use occurs. If consumptive use does occur, then permits can be obtained on a case-by-case basis from the Department of Conservation and Natural Resources. Additional permitting requirements may be necessary through the Division of Environmental Protection. Nevada is currently reworking its geothermal regulations; however, no regulations have been adopted. The process is expected to remain essentially as it is now, with some changes to specifically address the geothermal process. Table 28 shows the agencies involved in geothermal activities in Nevada.

New Mexico

The Geothermal Resources Act of 1967, passed by the New Mexico legislature, requires that all State lands only be leased for geothermal development through competitive bidding. Lease terms were initially for 5 years. The Act restricted the size of any lease to between 640 and 2,560 acres. It also prohibited any lessee from leasing more than 25,000 acres in New Mexico. The 1979 New Mexico legislature relaxed many of these constraints to extend the total acreage limitation from 25,000 to 51,200 acres and extended lease time limitations from 5 to 10 years. The State Lands Commissioner is given broad powers to impose any specific requirements or conditions on the lease.

In 1973, the responsibility for regulating geothermal development was taken largely by the Oil Conservation Division. It is responsible for drilling, development and production, and conservation and prevention of waste of geothermal resources. This general directive was followed, in 1975, by the Geothermal Resources Conservation Act. This Act prohibits waste and gives the Oil Conservation Division powers to prevent waste and protect correlative rights. Under the Act, the Oil Conservation Division may have access to records, require reports, regulate wells, limit and allocate production, and prevent discrimination in the buying, selling, and developing of geothermal resources.

The Energy Research and Development Act of 1975 created a fund, administered by the Energy Resources Board, to finance research and development projects in the energy field. The Act's specific purpose was to provide the means to seek solutions to fuel and energy problems through energy research and development to benefit the citizens of New Mexico in the fields of wind, solar,

Table 28. Agency and permit requirements in Nevada.

Agency	Permit responsibility	Processing time (months)
State		
Nevada Dept. of Conservation and Natural Resources		
Division of Water Resources	Licenses drillers, issues drilling permits, issues permits authorizing geothermal resources appropriation	12-24
Division of State Lands	Issues leases on state-owned land	12-24
Division of Environmental Protection	Enforces air and water quality standards	12-24
Division of Water Planning	General planning functions	12-24
Division of Minerals	Regulates geothermal exploration	12-24
Department of Energy	Reviews geothermal research and development policies	-
Nevada Bureau of Mines and Geology	Research responsibilities	-
Nevada Public Service Commission	Regulates uses of geothermal energy	-
Local		
Counties	Land use and conditional use permits	3

geothermal, fossil, nuclear, and all other research. The State generally supports new research and development programs connected with the geothermal field. Wetlands development could be a potential State-assisted research project.

Other State agencies are also involved in geothermal energy. The Energy and Minerals Department has powers to review all decisions of the Oil Conservation Division. The Department also assists developers. The State engineer has regulatory power through issuance of permits to drill wells or develop geothermal resources within declared underground basins. If geothermal wells or wetlands are established in or above a declared underground basin, then water right appropriations would be required from the State. The Environmental Improvement Division has regulatory power over air quality and over occupational health and safety.

Table 29 shows the agencies and time limits involved in development of geothermal resources in New Mexico.

Northern California

California has a very complete and complex set of regulations. California does not consider geothermal energy either a water or a mineral resource, but its own special entity. The general policy on geothermal development is one of protection of both the environment and the resource. There is a separation of water rights and geothermal rights, with a similar permitting structure.

The Division of Oil and Gas is primarily responsible for drilling procedures. The Water Resources Control Board governs surface and ground water quality.

There are some potential legal constraints in California. For example, San Diego Gas and Electric is working with a requirement in Imperial County that 100% of all geothermal water extracted must be injected. The county is primarily agricultural, and the State has said that subsidence cannot be tolerated. There are also increasing salinity problems in the Salton Sea. The State generally requires that up to 80% of the geothermal water extracted be injected. This is especially important in the Central Valley area, where ground water is used for agricultural purposes. The general permitting procedure in California and the agencies involved are shown on Table 30.

Oregon

Geothermal resources in Oregon are defined as those resources with temperatures greater than 120° C and/or those taken from wells deeper than 2,000 feet. The Department of Geology and Mineral Industries (DOGAMI) was given authority to regulate geothermal drilling by the 1971 Geothermal Resource Act. Shallow, low-temperature wells are now treated the same as common water wells and are regulated by the State Water Resources Department (WRD).

The WRD requires applications for permits to appropriate ground water for all ground water wells. The permit is issued by the Water Resources Director and requires certification that the applicant has existing ground water rights

Table 29. Agency and permit requirements in New Mexico.

Agency	Permit responsibility	Processing time (years)
State Engineer	Issues permit for well drilling and appropriating geothermal resources within declared underground basin.	1-2
Water Resources Division	Water rights.	
Environmental Improvement Division	Regulates air quality and occupational health and safety.	1-2

Table 30. Agency and permit requirements in Northern California.

Agency	Permit	Required for	Processing time
Department of Conservation Division of Oil and Gas	Geothermal Well Permit	Drilling, reworking, or abandoning geothermal well. Also applies to underground storage and waste disposal projects associated with geothermal production.	10 days
	Negative Declaration/ Environmental Impact Report Requirement	Determination of environmental impacts, alternatives, mitigations prior to development.	45 days-1 year
State Lands Commission	Geothermal Exploration or Prospecting Permits	Exploration for geothermal resources on state lands	10 days
Air Pollution Control District	Authority to Construct	Construction, modification or operation of a facility that may emit air pollutants from a stationary source.	6-9 months
	Permit to Operate	Obtained after Authority to Construct Permit and completion of construction or modification of facilities, but before beginning operation.	1 month
Department of Fish and Game	Stream or Lake Alteration Agreement	Activities that change the natural state of any river, stream, or lake.	
California Energy Commission	Notice of Intention and Application for Certification	Thermal power plants generating more than 50 megawatts and associated transmission lines.	2 years
Public Utilities Commission	Certificate of Public Convenience and Necessity	Construction or enlargement of a public utility system, facility, transmission line, or pipeline.	
The Reclamation Board	Encroachment Permit	All activities along or near the banks of the Sacramento and San Joaquin Rivers and their tributaries. Also applies to activities proposed within designated floodways in the Central Valley.	6 months
State Water Resources Control Board - Division of Water Quality	National Pollutant Discharge Elimination System (NPDES) Permit	Activities and facilities that discharge waste into surface waters, a confined pipe, or channel.	6 months
	Water Discharge Requirements	Facilities and activities that discharge waste into ground water or surface waters. Applies to soil erosion and runoff, but not to point source discharges into surface waters.	6 months
County Government	Land Use Permit - varies depending upon county	County approval of development	Variable; generally 1-3 months

for the proposed purpose and will put the water to beneficial use. If geothermal wells are located in "critical ground water areas," it will be more difficult to acquire appropriation permits. The WRD, in considering ground water appropriation applications, may impose conditions on approval as deemed necessary to protect public health, safety, and welfare.

No other WRD permits are required before drilling. A $2,000 bond is required, and drilling procedures must conform to ORS Chapter 690, "Rules and regulations prescribing general standards for the construction and maintenance of water wells in Oregon." The procedures established in these regulations would not constrain geothermal or wetlands habitat development.

DOGAMI requires permits for prospect wells and for geothermal production wells. Prospect wells are defined as wells less than 2,000 feet deep that are drilled as test wells; seismic shotholes; or for mineral exploration drilling, core drilling, or temperature gradient testing. Prospect well permit applications must include a plan of operation and hole location when submitted to DOGAMI with a $100 filing fee and $5,000 bond or security deposit. Applications are circulated to the Water Resources Director, the Director of the Department of Land Conservation and Development, the Director of the Division of State Lands, and any other appropriate agency. The permit can be issued in 30 days, and conditions can be imposed, including provisions for proper and safe abandonment of wells.

Geothermal production wells are those that are drilled to depths greater than 2,000 feet and contain geothermal resources greater than 250° F. Permit applications are referred to the State Water Resources Director, the State Fish and Wildlife Director, the State Forester, the Director of the Department of Environmental Quality, the Administrative Officer of the State Soil and Water Conservation Commission, the State Parks Superintendent, the Water Policy Review Board, the State Highway Engineer, the Director of the Department of Land Conservation and Development, the Director of the Division of State Lands, and other local agencies. A permit can be denied or conditioned based on responses from any of these agencies. If it is determined that the project meets all applicable regulations, DOGAMI can issue a drilling permit within 45 days upon receipt of indemnity bond for $10,000 for each well.

The Oregon Division of State Lands (DSL) maintains a one-stop leasing office for nearly all geothermal resources that underlie state-owned lands. These include all common school, indemnity, forest, higher education, veterans, highway, parks, and certain fish and wildlife lands. An exploration permit must be obtained from the DSL before any development. Exploration can proceed until a discovery is made or further exploration is abandoned. By proving the value of his discovery, the developer will be given a priority to enter into a lease. Application for a lease must include an environmental analysis and development and operations plan for the leasehold.

Oregon policy, as established by the 1979 legislature, states that all geothermal fluids shall be injected into the same reservoir from which withdrawn, unless it is determined by the agency responsible for well permitting that disposal by other means is in the public interest.

Legislation outlining this policy specifically mentions that disposal by other means includes secondary uses of fluids produced from electrical generation and direct applications for such uses as plant cooling, and agricultural, commercial, or industrial purposes. Use of geothermal effluents to create waterfowl wetlands would require the documentation of public benefits to be gained by developing wetlands and a demonstration that no subsidence problems would occur.

The WRD and DOGAMI are currently preparing legislation for consideration during the 1981 legislative session on geothermal effluent disposal. This information is not available for public review at present, and it is not certain what additional regulations may be required in 1981.

More than 50 of the 267 cities and counties in Oregon have known geothermal resources within their jurisdictions. Several more have been identified as having resource potential. Some local governments, such as the City of Klamath Falls, have been using geothermal resources for years. However, most local governments have limited knowledge and almost no experience in planning or managing geothermal resources. There are very few local city or county regulations, but it depends on the specific area where resources are developed. Some counties may require conditional use permits for exploratory drilling and associated development.

Table 31 summarizes the State agencies and their involvement in the permitting of geothermal resource development in Oregon.

Utah

The Utah Division of Water Rights retains the responsibility for overseeing geothermal development in Utah. Geothermal resource development is considered to be closely associated with water, and the division has applied laws governing water appropriation to geothermal development. The division has issued rules and regulations that apply specifically to geothermal exploration and development.

State regulatory requirements do not appear extensive, nor do they create any specific constraints. An exception to this may be water rights appropriations. Water rights applications will be required by the State. It is possible that downstream users could apply for water rights appropriations based on the expected discharge from potential wetlands. It would also have to be demonstrated that the development of the geothermal resource was not contributing to loss of some water rights (ground water withdrawal) elsewhere and that no other impacts to previous users would be expected.

The Utah Health Department has been extremely active and concerned about disposal. Some documentation will probably be necessary to show that there will be no health hazards or problems associated with surface discharge. Disposal by means of injection is not a written policy in Utah, but it is generally an opinion that injection should be used (Waystaff, personal communication). If proper documentation could be shown that there would be no health hazard or subsidence problems, then consideration could be given to establishing wetlands.

Table 31. Agency and permit requirements in Oregon.

Agency	Permit responsibility	Processing time (days)
Local cities and counties	Conditional use permit	30-60
Oregon Water Resources Department[a]	Ground-water appropriation permit	30
Oregon Water Resources Department[a]	Ground-water well drilling start card	1
Oregon Department of Geology and Mineral Industries[a]	Geothermal prospect well drilling permit	30
Oregon Department of Geology and Mineral Industries[a]	Geothermal production well drilling permit	45
Oregon Department of Environmental Quality[a]	Water pollution control facilities permit (wastewater, solid waste disposal)/NPDES permit	45
Oregon Department of Environmental Quality[a]	Notice of construction	60

[a] All these permits may not be required depending on further resource assessment.

Table 32 shows a compilation of various permits required by county, State, and Federal agencies in Utah. The time estimates are based primarily on information obtained from agency officials; in most cases, no statutory time limits exist for responsible agencies.

SOCIOECONOMIC CONSTRAINTS

Few socioeconomic constraints can be identified for wetlands disposal of geothermal effluent. Most of the potentially constraining socioeconomic elements in geothermal development result from actual development of the resource, such as drilling impacts of noise, air quality degradation, seismicity, and safety.

The primary socioeconomic constraint or impact that could occur is subsidence if effluent were used for wetlands development rather than being injected. Agriculture systems of irrigation, drainage, and tiling, as well as some public facilities, are based on existing slopes and have little tolerance to change. However, when a geothermal reservoir is capable of maintaining sufficient fluids by natural recharge, surface disposal for wetlands development can be used and is the least costly form of disposal. In some States, such as Oregon, this is viewed as an opportunity to enhance environmental quality by allowing creation of wetlands habitat along flyways in otherwise inhospitable environments. In this instance, a demonstration of public benefit would not be difficult.

Location of wetlands development is important. Attraction of waterfowl to certain areas, such as near airports or grain fields, may not be desirable. Wetlands also can provide mosquito, as well as other pest, breeding habitat.

Wetlands developed using industrial process wastewater will be temporary, dependent on the life of the industrial facility. Flow and quality of water to the wetlands will be a function of the industrial process and the capacity and quality of the geothermal reservoir. Seasonal fluctuations in the amount of the spent geothermal fluid can be anticipated (i.e., inverse correlation with space heating demands). Temporary shutdowns can also be anticipated related to emergency repairs and preventive maintenance; these are harder to predict than the seasonal fluctuations. If no other discharge occurs to the wetlands to replace the industrial wastewater, the wetlands will eventually cease to be and evolve into an upland upon termination of the industrial facility.

Creation of new wetlands, particularly in arid areas, can provide recreational, aesthetic, educational, and wildlife opportunities where they do not exist. Supplementation of existing wetlands can expand habitat opportunities for waterfowl and wildlife use, and increase quality of the wetlands network. Whether publicly or privately owned, wetlands creation or expansion can greatly add to diversity of an area for public enjoyment.

Development of a wetlands would also provide long-term open space preservation, which is often a concern in local land use planning efforts. In many States, tax benefits are provided by an open space assessment for such resource areas; this could provide considerable savings for the landowner who may otherwise be assessed at market value for the property.

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Table 32. Agency and permit requirements in Utah.

Agencies	Permit	Required before	Estimated time for issuance	Notes
County Agencies				
County Planning Commission	Zoning	Depends on county zoning ordinances	Variable	Already accomplished in some counties
County Clerk	Business license	Sale of electricity		
County Commission or Health Department	Health code enforcement Building inspection	Use of buildings	Variable	
State Agencies				
Division of State Lands	Lease state lands	Exploration or use of lands	Few days to 2-3 weeks	May be competitive bidding in some cases but that does not significantly increase issue time
	Special use permit	Surface disturbance (construction of plant)	Not known--possibly about about 2 months	Has not yet been applied for in Utah
Department of Transportation	Encroachment permits	Use of state highway lands for utility lines	Few days	Would be necessary for use of or crossing of state highway rights of way with utility lines such as power lines, water mains, sewage pipes, etc.
Division of Water Rights	Permits for thermal gradient wells	Drilling of thermal gradient wells	Few days to few weeks	Letter of approval
	Permit for exploratory "test" wells	Drilling of exploratory wells	Few days to few weeks	Letter of approval
	Notification of reservoir test	Reservoir tests		
	Appropriation of water	Use of water	6 months or longer	
	Production and injection wells			Covered by appropriation of water if included in the plan of operations
Environmental Health Services				
Bureau of Water Quality	Construction plan review and permit	Construction	About 2 months	Pre-planning workshop
	Public water supply approval	Use of building	1 to 2 months	
	Draft and certification of discharge permit (sanitary)	Use of building	1 to 2 months	In conjunction with EPA, which issues the permit
	Liquid waste disposal system approval	Use of building	1 to 2 months	
Bureau of Air Quality	Construction plan review and approval	Construction	About 3 months	In conjunction with EPA
	Discharge permit	Use of plant	About 3 months	Plant discharges

Table 32. (concluded)

Agencies	Permit	Required before	Estimated time for issuance	Notes
Bureau of Solid Waste Management	Solid waste disposal			
Department of Business Regulation	Certificate of convenience and necessity or approval of contract between utility and electricity producer	Sale of electricity	3 to 4 months	Certificate of convenience and necessity if utility owns plant; if utility buys power, approval of contract is required

If the wetlands effluents are being used secondarily (i.e., irrigation), the supply cannot be guaranteed to the user because of the inherent uncertainties, both short- and long-term. Generally speaking, the uncertainties are probably not great and the secondary user would have a reasonably dependable water supply.

RESOURCES CONSERVATION AND SUBSIDENCE

INTRODUCTION

The geothermal resource conservation aspects of wetlands disposal were evaluated, recognizing that surface disposal of geothermal fluids appears to have the potential of leading to subsidence and reservoir depletion where natural replenishment does not occur. Known and justifiably inferred geologic and hydrologic characteristics were evaluated to determine whether resource conservation and subsidence were potential issues; both generically, and for sites identified in Section 5 as usable for wetlands disposal.

METHODS

A literature search of existing information was made to effectively evaluate the usability of a site for disposal of spent fluids, considering resource conservation and subsidence. This information included the following factors.

- Site geology; surficial and subsurface.
- Geology of the geothermal resource reservoir.
- Site hydrology.
- Effects of subsidence.
- Current research in subsidence.
- Effects of hydrocompaction.
- Technology of injection.

This information was evaluated generically and for the sites identified in Section 5. Information was sought from agencies, research concerns, and geothermal project operators but was generally unavailable.

Limitations

This chapter is for use in categorizing areas generically and specifically as potentially usable or unusable for wetlands disposal of spent fluids. It does not include, nor imply inclusion, of statements of existing conditions that are adequate for preliminary or final design of a wetlands disposal area. Statements describing existing site conditions are based on limited data and were not confirmed by site visits.

Because geothermal exploration and development is a rapidly developing field, assumptions made in this report may not reflect state-of-the-art knowledge when applied to future projects.

RESOURCE CONSERVATION

Reservoir Theory

The geologic setting of a reservoir not only limits the type, size, and depth below surface of the source, but also affects the potential for subsidence and the susceptibility of the resource to replenishment by injection. The nature of the geothermal heat source controls the options for resource development, which in turn affect subsidence potential and the feasibility of injection.

Geologically Controlling Factors

According to Weiss et al. (1979) and others, two basic types of reservoir rock models exist: the volcanic and the volcano-tectonic models. Both types occur in areas of thinner than normal crust where shallow, recent volcanism is nearby.

Volcanic model. In the volcanic model, the reservoir consists of relatively homogeneous, crystalline, igneous or metamorphic rocks that are faulted, fractured, and saturated with fluids. Heat is supplied to the reservoir from a shallow magma chamber by conduction. When fluid in the fractures is heated, large scale thermal convection cells develop. These cells are modified by the faults and fractures present.

The reservoir is usually bounded by faults that conduct water from fluvial, lacustrine or meteoric origin to recharge the reservoir. Sometimes interior faults are present that conduct hydrothermal solutions to the surface. These surface manifestations are one or more of many forms, such as springs, steam, or hydrothermal alterations to the rocks. Sometimes shallow heated aquifers are present. Most cases of the volcanic model consist of some of the above-mentioned features in various proportions and importances.

Volcano-tectonic model. In the volcano-tectonic model, the reservoir consists of porous, clastic sediments with intergranular permeability. These sediments may contain less permeable layers of clay or volcanic flows.

The reservoir is usually bounded by faults or areas of lower permeability. Heat is conducted via a convecting current in this system. A heat source present in thin, crystalline, crustal rocks is conducted upward to sedimentary deposits that contain ground water. The water is heated, and rises before circulating back downward, forming the convecting current. Sometimes faults that extend into the basement rocks may also conduct fluid up to this convection cell.

The convecting current circulates upward until it is stopped by the reservoir caprock. This caprock can be an impermeable layer of sedimentary origin such as a shale or one produced by the chemical precipitation of the fluids, such as a sinter.

More permeable sediments may overlie the caprock and contain ground water aquifers. Both the bounding faults and downward percolation from these overlying aquifers can recharge the system. This recharge may occur through more permeable parts of the caprock at some distance from the convection cell. Surface manifestations are generally less common in this type of system.

Based on the geologic setting of a reservoir, the potential for subsidence is less significant for the volcanic model. In the volcano-tectonic model, subsidence potential is likely unless spent fluid is injected (Weiss et al. 1979).

Thermally Controlling Factors

According to Atherton et al. (1976), subsidence potential can also be estimated based on the type of reservoir fluid. Hydrothermal systems, defined as those that contain hot water and/or steam, and geopressured systems, defined as those where reservoir fluids exist at greater than hydrostatic pressure, are thought to exhibit the greatest potential for subsidence, compared with hot rock resources and magma resources. The reason is that removal of the resource from these systems causes significant pore-pressure reduction.

In hydrothermal systems, the pore-pressure is primarily determined by the type of fluid in the rocks. Systems containing mostly liquid are most prone to subsidence. Two-phase, liquid-dominated systems are next likely to experience subsidence; and vapor-dominated, two-phase systems are least likely to subside. The latter is due to the geological framework of dry-steam fields, where the rock must be competent for the reservoir to exist at all. Therefore, the pore spacing stays relatively the same with or without the presence of steam.

In geopressured systems, the pore-pressure actually supports the rock strata above the resource and withdrawal of fluids may stimulate subsidence.

Reservoir Depletion

When a geothermal resource is recovered, there is an accompanying drop in pressure. If the resource is confined within the pores of the reservoir rock, a drop in pore pressure will result if the subsurface void that is created is not continually being recharged. The larger the change in fluid pressure, the greater the load transferred to the rock matrix and hence, the greater the potential for compaction. This increases subsidence potential and might require injection in specific cases. If injection is specified, it should take place below the impermeable layers to confine the fluid and prevent upward migration.

A two-phase reservoir is advantageous because steam is more easily used. Liquid-dominated reservoirs can become two-phase reservoirs if reinjection does not occur. However, subsidence is likely to result. The costs of subsidence must be balanced against the benefits of a steam system. If injection in a two-phase system takes place, it should be in the water region. This will cause less interference with the produced fluid and will maintain reservoir pressure with energy extraction.

Specific information on size of resource and amount of depletion to date was not available for most of the sites chosen for this study. This lack of information is primarily because of low development to date.

SUBSIDENCE

Subsidence is the collapse of the ground due to development of subsurface voids, or reduction in volume of subsurface materials either naturally or artificially. It results from volume changes without benefit of a superposed load.

The most widespread cause of extensive subsidence is the withdrawal of ground water by pumping. Subsidence due to the production of hydrocarbon fluids is similar to that caused by withdrawal of ground water. In comparing geothermal areas with areas of hydrocarbon and ground water subsidence, the following major differences were noted.

- Lithology is highly variable with geothermal systems; but it is usually sand with interbedded clays and shales for the other two systems.
- Median production depth is shallowest in ground water and deepest in hydrocarbon systems.
- Deformation due to faulting is common in geothermal and hydrocarbon systems; it is rare in ground water systems.
- Production areas are largest in ground water systems prone to subsidence.
- Pressure decline is least in ground water systems and is greatest in geopressured geothermal systems.

In situations of hydrocarbon withdrawal, subsidence can be remedied by injection of spent fluids after it is detected as a problem. The theory is that if pressure in a reservoir is maintained at some level below the original reservoir pressure--sufficiently high to avoid dewatering adjacent mudstones and shales--subsidence can be controlled successfully (Crow, undated). Additional information concerning the relationship between ground subsidence and the extraction of fluids for nongeothermal purposes can be found in Poland (1976) and Poland and Davis (1969).

Subsidence ground movements due to geothermal development may be one of five types.

- Subsidence or rebound of the land surface due to fluid pressure changes.
- Lateral ground movement due to induced fluid pressure gradients.
- Vertical ground movement due to thermal expansion or contraction of the rocks.
- Tectonic faulting or folding.
- Landslides and mass wasting.

(The latter two types are unrelated to resource production.)

Impacts of Subsidence

Impacts of subsidence on existing land uses will depend to a great extent on the magnitude of subsidence experienced. Gravity-dependent systems, such as irrigation systems, are particularly sensitive to even minor changes in topography. Other land uses that require solid foundations, such as buildings, could probably withstand minor amounts of subsidence but could be severely impacted if major fault movements occur. Land uses that do not depend on gravity systems or structural foundations are generally less impacted by subsidence. Table 33 presents general land use categories and their potential for impact from subsidence.

Concurrent Effects of Ground Water Withdrawal

The demand for resources in overlying strata may create subsidence unrelated to geothermal exploitation. Therefore, the potential effects of subsidence due to geothermal activity become more complex to predict.

The best documented study of effects of ground water withdrawal in a geothermal area is for Roosevelt Hot Springs and Raft River, Idaho (Grimsrud et al. 1978). At these sites, it has been documented that when 150 to 300 feet of alluvium were dewatered by pumping to meet irrigation demands, compaction of the alluvium occurred. Apparently, in areas where an extensive ground water aquifer overlies the geothermal resource, pumping out of this cold water can create subsidence over an area larger than that of the geothermal resource. A regional tilt of 1.5° was documented over an area extending from the Utah-Idaho border to Burley, Idaho.

Hydrocompaction

Hydrocompaction is subsidence in arid materials due to the injection of water at the surface. The most susceptible materials are alluvial and wind-blown silts, present in areas where the water table is low and the overlying soils are dry. Because the materials are moisture deficient and have a low density, they may actually be compacted when water is introduced to the surface. The water loosens the bonds between particles so that the weight of the overburden compacts the soil layers at the expense of former pore space. Hydrocompaction usually occurs in soils in the surface to 65 m depth. Consideration should be given to susceptibility to hydrocompaction in choosing potential wetlands sites.

Induced Seismicity

The only evidence for induced seismicity has been documented at Rocky Mountain Arsenal waste disposal well near Denver, Colorado, and at the Rangely Oil Field in northwestern Colorado. Because injection was occurring in dry formations, seismic events were triggered (Weiss et al. 1979). There is no evidence that injection in relation to geothermal production in any way increases the seismicity of a region.

Table 33. General land uses and their potential for impact from land subsidence.[a]

	Impact potential	
Minimal	Moderate - severe	Severe
Open space	Irrigated agricultural land	Oil/gas pipelines
Forestry-tree farming		Dams
	Public services	
Nonirrigated land	Sewerlines	Transportation systems
Agricultural-grazing	Waterlines	Roads
		Railroads
Natural resource extraction	Structures	Bridges
Surface mining		Paved airstrips
Transportation systems		Natural resource extraction
Nonpaved roads		Underground mining
Nonpaved airstrips		

[a] Severity of impacts highly dependent on level of subsidence experienced.

GENERIC CRITERIA

Table 34 shows selected generic criteria for geologic factors and for reservoir factors, and how these relate to subsidence potential. Basically, the potential for subsidence is increased when the structural integrity of the reservoir rock is lessened due to fluid withdrawal from its pores. Subsidence occurs when the ability of the substance to be supported with air in pore spaces is less than its ability to be supported with fluid in the same space. Therefore, withdrawal in a liquid-dominated system is more likely to result in subsidence.

SITE DESCRIPTIONS

Sites to be evaluated for subsidence potential are listed by State in Section 5 of this report as direct use areas. General geologic and reservoir conditions of geothermal use areas of each State are given. Brief descriptions of the geology, geothermal resource, and subsidence potential are presented (Table 35). The site geologic information is based primarily upon State geologic maps. Scales ranged from 1:500,000 to 1:1,000,000.

The hydrothermal resource information is based primarily on baseline studies (New Mexico, Nevada, Idaho, and Montana) and other recent State reports. The level of detail of information varied for sites within each State.

The subsidence potential is a judgment based upon application of the generic criteria previously mentioned, and subject to the limitations stated previously. Sites generally are moderate or extreme in susceptibility, and are ranked relative to subsidence potential in the summary.

Idaho

Nine geothermal use areas were identified in Idaho in Section 5 of this report. Potential high-temperature (150°-200° C) reservoir resources in Idaho are thought to be most likely in two general areas: southeast Idaho, and along the margins and within the Snake River Plain. Among the nine, areas 6, 7, 9, 10, and 16 discussed in this report are within the Snake River Plain (EG&G, Inc. 1978).

As of 1979, there were no confirmed reservoirs with temperature greater than 150° C. There are about 60 springs and wells with temperatures greater than 40° C identified within the State (EG&G, Inc. 1978).

Site No. 5 is located in Adams County, in west-central Idaho, in the Rocky Mountains geologic province. The geothermal source is a spring, in Cretaceous igneous rocks (crystalline basalt plutons). The site is near the faulted, eroded boundary of Idaho Batholith rocks and Columbia River Group rocks. There is a major fault on the west and a minor fault on the east.

Although the geothermal resource system has not been studied in detail, it is thought to be a geothermal convection system with a hot water source. The spring is on a north-south oriented drainage divide. Cascade Reservoir is located east of the site.

Table 34. Generic criteria for geologic and reservoir factors (Altherton et al. 1976; Grimsrud et al. 1978; Weiss et al. 1979).

Factors	Increases subsidence potential	Decreases subsidence potential
Geologic		
Hydrothermal Alteration	If it occurs on igneous and metamorphic rocks because strong minerals are changed to weak ones	If it occurs on sedimentary rocks because they become indurated, creating a stronger interlocking texture
Preconsolidation	If it occurs in geopressured systems because the reservoir materials only bear a fraction of the geostatic stress	
Cementation		If it occurs on sedimentary rocks because compressibility is reduced
Interstitial clay	If it occurs on sedimentary rocks because it increases the ability of sand grains to compress	
a. Montmorillonite	Most compressible clay	
b. Mica (few %)	Drastically increases compressibility because grains bend and break easily.	
Feldspar	Susceptible to fracturing	
Calcite and soft lithics	Susceptible to plastic deformation	
Grain size uniformity	If it is poor on sands, it increases compressibility	If it is good on sands, it decreases compressibility
Thickness of fine-grained sedimentary beds	If they occur in many thin beds	If they occur in few thick beds
Interbedded volcanic flows, welded tuffs, and shallow flows		If interbedded with reservoir materials will reduce downward transmission of effective stress
Overburden thickness		If it is high, reduces the tendency to deform and thus less compaction is likely to be transmitted to the surface
Overburden competence		If it is high, increases resistance bending and expansion
Fracturing	By increasing hydraulic communication	

Table 34. (concluded)

Factors	Increases subsidence potential	Decreases subsidence potential
Geologic (continued)		
Faulting	If normal faulting, because it results from tensional stress. If strike-slip faulting due to shear stress, because it contributes to grain rearrangement and compaction	If reverse or thrust faulting, because it results from compressive stress
Folding	If flat or broadly arched sediments with dips less than 25 degrees, because of susceptibility to bending	If tightly folded strata with flank dips greater than 25 degrees, because of inherent structural strength
General Rock Type	If sediments because of higher porosities	If igneous or metamorphic rock
Near surface eolian or arid alluvial soils	Potential for hydrocompaction	
Reservoir		
Reservoir width	If large because the greater the tendency for the overburden to deform under its own weight and from the stress of production	
Phase	If all-liquid	If vapor-liquid or all-vapor
Rate of withdrawal	If large volume, with large drop in fluid level, over a long time, over an extensive area, with no flashing	If small volume with no drops in fluid level, and extensive, continual flashing

Table 35. Summary of subsidence susceptibility.

Sites (number and county)	Geologic factors			Reservoir factors		
	High potential	Moderate potential	Low potential	High potential	Moderate potential	Low potential
Idaho						
Site No. 5 Adams County	Normal faulting		General rock type--igneous	All-liquid or liquid-dominated system		
Site Nos. 6 and 7 Blaine County			Thrust faults; general rock type--igneous	All-liquid system		
Site No. 8 Boise County	Normal faulting		General rock type--igneous	All-liquid or liquid-dominated system		
Site Nos. 9 and 10 Camas County		Alluviated volcanic terrain	Lack of faulting	All-liquid system		
Site No. 15 Elmore County	Normal faulting	Reservoir materials--interbedded volcanics and weld tuffs		NA[a]		
Site No. 16 Gooding County	~~Normal faulting~~ Hydrothermal alteration may occur in basalts	Alluviated volcanic terrain		All-liquid system		
Site No. 21 Custer County	Volcano-tectonic model with sinter caprock		Lack of faulting	All-liquid system		
Montana						
Site Nos. 2 and 3 Jefferson County	Fractured crystalline rock		Lack of faulting	All-liquid system		
Site Nos. 16 and 17 Sanders County	Buried fault in river valley			All-liquid system		
Site Nos. 18 and 19 Beaverhead County	General rock type--sediments	Alluviated volcanic terrain	Lack of faulting	All-liquid system		

Table 35. (concluded)

Sites (number and county)	Geologic factors			Reservoir factors		
	High potential	Moderate potential	Low potential	High potential	Moderate potential	Low potential
Oregon						
Site Nos. 14, 16, 17, 19, 20, and 21 Klamath County	Normal faulting	Alluviated volcanic terrain; interbedded volcanic flows and welded tuffs			Liquid-dominated system	
Site Nos. 15 and 18 Klamath County	Normal faulting	Alluviated volcanic terrain; interbedded volcanic flows and welded tuffs			Liquid-dominated system	
Northern California						
Site No. 3 Lassen County	General rock type--sediments; normal faulting				Hot liquid-dominated	Vapor-dominated
Site No. 6 Lassen County	General rock type--sediments; normal faulting				Hot liquid-dominated	Vapor-dominated
Site No. 13 Modoc County	Normal faulting	Sediments with interbedded volcanics and tuffs			Hot liquid-dominated	Vapor-dominated
Nevada						
Site Nos. 15, 16, 17, 18, and 19 Nye County	Normal faulting	Alluviated volcanic terrain			Hot liquid-dominated	Vapor-dominated
Site Nos. 63, 64, 65, 66, 67, and 68 Washoe County	Normal faulting	Alluviated volcanic terrain			Hot liquid-dominated	Vapor-dominated
Site Nos. 79 and 80 White Pine County	Normal faulting	Alluviated volcanic			Hot liquid-dominated	Vapor-dominated
New Mexico						
Site No. 9 Catron County	General rock type--sediments	Tuffs and basalt flows		All-liquid		
Site Nos. 12 and 15 Sandoval County	NA				NA	
Site No. 18 Socorro County	Normal faulting		General rock type--igneous	All-liquid		

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[a] NA = not available.

The geothermal reservoir at this site is a volcanic model, which makes it geologically less susceptible to subsidence. It probably has all-liquid or liquid-dominated reservoir fluid that is geothermally pressured, which makes it highly to moderately susceptible to subsidence. Hydrocompaction should not be a problem here. Other factors influencing subsidence potential are the general rock type (igneous), which decreases susceptibility, and the type of faulting (normal) which increases the susceptibility.

In summary, available information on geologic and reservoir factors indicates that Site No. 5 is potentially moderately susceptible to subsidence (Table 35).

Sites Nos. 6 and 7 are located in Blaine County, in the Snake River Plain geologic province. Both resources are springs located in Paleozoic and Mesozoic volcanic strata. They are near a northwest-southeast trending fault zone in the Sun Valley area. Site No. 6 apparently is in Lower Permean thrusted marine detritus. East-trending thrust faults are located south of these sites.

Although the geothermal resource systems have not been studied in detail, this portion of the Snake River Plain is thought to contain hot water reservoir temperatures in excess of 90° C. Site No. 6 is part of Gayer Hot Springs, which have a temperature of 71° C. It is not known if these systems are part of a continuous system.

The geothermal reservoirs at these sites are volcanic models, which makes them geologically less susceptible to subsidence. They are probably all-liquid or liquid-dominated reservoir fluids that are geothermally pressured, which makes them susceptible to subsidence. Hydrocompaction should not be a problem here. Other factors influencing subsidence are the general rock type (igneous), and the type of faulting (thrust), both of which decrease susceptibility.

In summary, available information on geologic factors indicates that Sites Nos. 6 and 7 are potentially low in susceptibility to subsidence, but reservoir factors increase its potential to moderately susceptible to subsidence (Table 35).

Site No. 8 is located in Boise County, in the Rocky Mountains geologic province. The geothermal source is a spring in igneous rocks (granodiorite plutons). A major north-trending fault is west of the site. Minor northeast-trending faults are west of the site. A major dike swarm is east of the site.

Although the geothermal resource system has not been studied in detail, it is part of Boise Hot Springs, a series of east-trending springs in this area.

The geothermal reservoir at this site is a volcanic model, which makes it geologically less susceptible to subsidence. It probably has all-liquid or liquid-dominated reservoir fluid that is geothermally pressured, which makes it highly to moderately susceptible to subsidence. Hydrocompaction should not be a problem here. Other factors influencing subsidence potential are the general rock type (igneous), which decreases susceptibility, and the type of faulting (normal) which increases the susceptibility.

In summary, available information on geologic and reservoir factors indicates that this site is potentially moderately susceptible to subsidence (Table 35).

Sites Nos. 9 and 10 are located in Camas County, in the Snake River Plain geologic province. The springs are located in Quaternary alluvium which overlies Snake River volcanics at the margin of the Idaho batholith. Site No. 10 is on a buried fault in a creek; Site No. 9 is on a creek oxbow. Both sites are northwest of Twin Lakes Reservoir.

These sites are in the Wardrop Hot Springs area, which is a high-temperature system included in the Camas Prairie hot springs area (Muffler 1979).

The geothermal reservoirs at these sites are alluviated valleys in volcanic terrain, which makes them intermediate between volcanic and volcano-tectonic models. Geologically they are more susceptible to subsidence than volcanic models. They are probably all liquid systems that are geothermally pressured, which makes them more susceptible to subsidence. Hydrocompaction should not be a problem here. The general lack of faulting in this area decreases the susceptibility to subsidence.

In summary, available information on geologic factors indicates that Sites Nos. 9 and 10 are potentially moderately low in susceptibility to subsidence, and reservoir factors increase its potential (Table 35).

Site No. 15 is located in Elmore County, in the Rocky Mountains geologic province. The geothermal resource is a well probably drilled into Pliocene silicic welded tuff, ash, and flow rock. A spring occurs near the site, to the northwest. Most faults in the area trend northwest. A major lineation is located south of this site.

The geothermal reservoir at this site is a volcano-tectonic model, which makes it geologically more susceptible to subsidence. Its geothermal fluid characteristics are not known. Other factors influencing subsidence potential are type of faulting (normal), which increases the susceptibility to subsidence; and the interbedded volcanic flows, welded tuffs, and ash flows which decrease the susceptibility to subsidence.

In summary, available information on the geologic factors indicates that Site No. 15 is moderate to moderately high in potential susceptibility to subsidence.

Site No. 16 is located in Gooding County, in the Snake River Plain geologic province. The geothermal resource is a spring in Quaternary stream or lakebed deposits, overlying olivine basalts. The site is due north of Bliss, south of the northwest-trending fault belt of the Challis Group volcanics, at the northern boundary of the Snake River Plain province.

This site is northeast of the Thousand Springs area, which may form a regional coldwater aquifer that recharges the area. The spring is included in the White Arrow Hot Springs that have a temperature of 65° C. It is considered a high-temperature system (Muffler 1979).

The geothermal reservoir at this site is an alluviated valley in volcanic terrain, which makes it intermediate between volcanic and volcano-tectonic models. Geologically, it is more susceptible to subsidence than a volcanic model. It is probably an all-liquid system that is geothermally pressured, which makes it more susceptible to subsidence. Hydrocompaction should not be a problem here. Other factors influencing subsidence are the type of faulting (normal) and the presence of olivine in the basalt, making hydrothermal alteration likely. Both factors increase subsidence potential.

In summary, available information on the geologic factors indicates that Site No. 16 is moderately high in potential susceptibility to subsidence, and reservoir factors increase its potential (Table 35).

Site No. 21 is located in Custer County, in the Rocky Mountains geologic province. There is little faulting in the area. The resource is a spring in travertine and sinter, probably over a Cretaceous granodiorite intrusive pluton. Circulation is along a structural trend in the Idaho Batholith (Muffler 1979).

The geothermal spring is probably associated with Loon Creek Hot Springs that have temperatures of 46-58° C and traces of H_2S smell.

The geothermal reservoir at this site is a volcano-tectonic model, which makes it geologically more susceptible to subsidence. The extent of its travertine and sinter caprock is not known. It is probably a liquid-dominated reservoir fluid that is geothermally pressured, which makes it more susceptible to subsidence. Hydrocompaction should not be a problem here. The general lack of faulting in the area decreases subsidence potential.

In summary, available information on geologic factors indicates that Site No. 21 is potentially moderately highly susceptible to subsidence, and reservoir factors increase its potential (Table 35).

Montana

The geothermal use areas identified for Montana in Section 5 of this report are geothermal convection systems that occur in the Boulder batholith region. These systems appear to be isolated and small. Over 100 thermal springs are known in Montana, with over 60 having temperatures less than 32° C (Muffler 1979). The temperatures of the resource areas identified for this study range from 40° to 60° C.

Sites Nos. 2 and 3 are located in Jefferson County, in the Boulder batholith region of the Northern Rocky Mountains geologic province. They are springs in Tertiary Boulder batholith and related stock, which is mostly quartz monzonite. They appear to be situated north and south of an anticline divide in the batholith, near Boulder River. A nearby dike trends north-northeast.

Site No. 2 is part of the Alhambra (Sunnyside) Hot Springs with temperatures of 57° C. Site No. 3 is part of the Boulder Hot Springs. Both are hot water geothermal convection systems.

The reservoirs at these sites are volcanic models, which makes them less susceptible to subsidence. The geothermal reservoir fluid is an all-liquid convection system, which makes it more subceptible to subsidence. Other factors influencing subsidence are the general rock type (igneous/metamorphic) and the relative absence of faults, both of which decrease the susceptibility to subsidence. Hydrocompaction should not be a problem here.

In summary, available information on the geologic factors indicates that Sites Nos. 2 and 3 are moderately low in potential susceptibility to subsidence, but the reservoir type increases the potential susceptibility (Table 35).

Sites Nos. 16 and 17 are located in Sanders County, in the Boulder batholith region of the Northern Rocky Mountains geologic province. The resources are springs in Pre-Cambrian Ravalli group sediments that have been intruded by diabase and diorite dikes. These sites are near a contact between the younger dike and the older sediments. The sediments are low-grade metamorphosed schists. A concealed fault runs northwest-southeast along the Little Bitteroot drainage.

Site No. 16 is part of the Camas Hot Springs, with temperatures of 45° C. Site No. 17 is part of Quinn's Hot Springs, with temperatures of 43° C, and is on a drainage divide between north and south flowing streams. Both are hot water geothermal convection systems.

The geothermal reservoirs at these sites are volcano-tectonic models, which make them more susceptible to subsidence. The reservoir fluid is an all-liquid hydrothermal convection system, which makes it more susceptible to subsidence. Other factors influencing subsidence are the metamorphism of the sediments into schists and the relative absence of faults, both of which decrease the susceptibility to subsidence. Hydrocompaction should not be a problem at this site.

In summary, available information on geologic and reservoir factors indicates that Sites Nos. 16 and 17 are potentially moderately susceptible to subsidence.

Sites Nos. 18 and 19 are in Beaverhead County, in the Boulder batholith region of the Northern Rocky Mountains geologic province. The resources are springs in Quaternary alluvium which overlies Tertiary Boulder batholith and related stock. The source rock is mainly quartz monzonite.

Site No. 18 is part of the Elkhorn (Polaris) Hot Springs, with temperatures of 49° C. Site No. 19 is part of the Jackson (Jardine) Hot Springs with temperatures of 58° C. Both are hot water geothermal convection systems. Deep circulation in fault zones occurs at Jackson (Muffler 1979).

The geothermal reservoir at this site is an alluviated valley in volcanic terrain, which makes it intermediate between volcanic and volcano-tectonic models. Geologically it is more susceptible to subsidence than a volcanic model. It is probably an all-liquid system that is geothermally pressured, which makes it more susceptible to subsidence. Hydrocompaction is not likely to be a problem here. The general lack of faulting in the area lessens the susceptibility to subsidence.

In summary, available information on the geologic factors indicates that Sites Nos. 18 and 19 are potentially moderately susceptible to subsidence, and the reservoir factors increase the potential susceptibility (Table 35).

Nevada

Thirteen geothermal use areas were identified in Nevada in Section 5 of this report. All of these sites lie within the Basin and Range physiographic province, characterized by north-trending mountain blocks separated by alluvial filled basins. Heat flow throughout the province is high, and it is especially high in northern Nevada. The mountain and valley blocks are separated by faults that have as much as 3,000 m of vertical displacement. These range-front faults form conduits for the deep circulation of meteoric water, and thus many of the systems are powered by geothermal convection. The Steamboat Springs geothermal system, a high-temperature resource (>150° C), is believed to be related to igneous activity.

Sites Nos. 15-19 are located in Nye County, in the Basin and Range geologic province. They consist of springs (15, 16, 17) and wells (18, 19) in Quaternary alluvium overlying Lower Volcanics of silic tuffs, rhyolite, andesite, and related rocks. There is a high angle fault on the west where volcanic intrusives and other basalt are exposed to the south.

The temperature range is 80° C to 100° C (EG&G, Inc. 1978). These moderate-temperature geothermal systems are part of the Darrough's Hot Springs area.

The geothermal reservoirs are volcano-tectonic models, which are more likely to experience subsidence. The fluids are either hot liquid-dominated or vapor-dominated, of which vapor-dominated lessens the susceptibility to subsidence. Because of climatic conditions, hydrocompaction potential should be considered in future studies. Normal faulting and sediments containing the aquifer increase the susceptibility to subsidence.

In summary, available information on the geologic factors indicates a moderately high to high subsidence potential, but the reservoir conditions lessen this potential (Table 35).

Sites Nos. 63-68 are located in Washoe County, in the Basin and Range geologic province. The resources consist of wells (63, 64, 65) and springs (66, 67, 68) in Upper Volcanics. They are located at the north end of a high-angle fault, with granodiorite intrusives of Tertiary age. Major faults trend southwest until about 20 miles north of the site, where they trend northwest. Quaternary alluvium overlies the volcanics.

The geothermal systems are part of the Steamboat Springs area. The springs here discharge from an extensive sinter (siliceous hard pan encrustation) apron. The maximum temperature in wells is 186° C (Muffler 1979); the springs range from less than 50° C to almost 100° C (EG&G, Inc. 1978).

The geothermal reservoirs are volcano-tectonic models, which are more likely to experience subsidence. The fluids are either hot liquid-dominated or vapor-dominated, of which vapor-dominated lessens the susceptibility to subsidence. Because of climatic conditions, hydrocompaction potential should be considered in future studies. Normal faulting and sediments containing the aquifer increase the susceptibility to subsidence.

In summary, the available information on geologic factors indicates a moderately high to high subsidence potential for Sites Nos. 63-68, but the reservoir conditions lessen this potential (Table 35).

Sites Nos. 79 and 80 are located in White Pine County, in the Basin and Range geologic province. The resources are springs in Quaternary alluvium overlying Paleozoic carbonates and Tertiary intrusives. They are located at the north end of a high-angle fault.

These two sites are part of the Warm Springs geothermal convection system, which is fed by circulation in deep range-front faults. Temperatures range from 21° to 72° C.

The geothermal reservoirs are volcano-tectonic models with a sinter caprock, making them more likely to experience subsidence. The fluids are probably liquid-dominated, which increases the susceptibility to subsidence. Another factor increasing this potential is the type of faulting (normal). Because of prevailing climatic conditions, hydrocompaction potential should be considered in future studies.

In summary, the available information on geologic and reservoir factors indicates a moderately high to high subsidence potential for Sites Nos. 79 and 80 (Table 35).

New Mexico

Four geothermal use areas were identifed in New Mexico in Section 5 of this report. They occur in the Basin and Range physiographic province and its special feature, the Rio Grande Rift.

Hot-spring activity in New Mexico generally corresponds to the regions of young volcanism and high heat flow. One area of high heat flow is along the western margin of the Rio Grande Rift near Socorro. Here, a sill-like magma body is located at a depth of about 18 km (EG&G, Inc. 1978). Site No. 18 is in this area. In southwestern New Mexico, the thermal anomaly is associated with the north-trending Basin and Range structures. Site No. 9 is in this area. The Rio Grande Rift and adjacent regions have had volcanic activity from about 10,000 to 26 million years ago (EG&G, Inc. 1978). The rift formed due to uplift of the earth's mantle. The corresponding heat source gave rise to activity at Sites Nos. 12 and 15.

Site No. 9 is located in Catron County in the Basin and Range Province of southwestern New Mexico. It is in an area of Tertiary and Quaternary sedimentary rocks, basaltic lavas, and rhyolitic tuffs. Deep circulation probably occurs along normal faulting.

The geothermal resource is a spring with temperatures ranging from 27° to 66° C.

The geothermal reservoir is a volcano-tectonic model, all-liquid system, which makes it most susceptible to subsidence. The potential for hydrocompaction is not known.

In summary, available information shows that both geologic and reservoir factors may increase the potential susceptibility to subsidence, making Site No. 9 potentially highly susceptible to subsidence (Table 35).

Sites Nos. 12 and 15 are a spring and a well in the Rio Grande Rift geologic province. The heat source is probably magmatic. Because so little is known about these sites, it is not possible to evaluate potential susceptibility to subsidence.

Site No. 18 is located in Socorro County in the western part of the Rio Grande Rift. The reservoir rock is probably Tertiary volcanics.

The geothermal resource is a spring, which has a temperature of 35° C (Muffler 1979). Deep circulation through a fault zone drives the geothermal convection system.

The reservoir is a volcanic model and therefore is less susceptible to subsidence. The reservoir fluid is an all-liquid system, which increases the susceptibility to subsidence. The Rio Grande Rift contains many normal faults, which increase the potential for subsidence.

In summary, available information shows the reservoir conditions may increase the potential for subsidence in Site No. 18, but the geologic factors do not, indicating a moderate potential for subsidence (Table 35).

Northern California

Three geothermal use areas were identified for northern California. All are located in the Basin and Range physiographic province. These sites are in the Modoc Plateau area of northeastern California, which consists of a series of northwest to north-trending block-faulted ranges, with intervening basins filled with basalt flows, volcanic cones, and lake deposits. Disruption of drainage occurred due to faulting or volcanism. Faulting and volcanism also were continuous from Miocene to Recent time. Lake deposits underlay the alluvium on valley floors, with deposition continuing today.

The thermal blanket effect of the thick layer of sedimentary rocks in many of the valleys of the Basin and Range Province results in local increases of an already high thermal gradient. The complex pattern of faulting provides conduits for deep circulation of waters. These two factors, plus young volcanism in many areas, combine to produce hotwater convection systems.

Site No. 3 is located in Lassen County, in the Basin and Range geologic province. The resource is a spring in Quaternary playa deposits near Honey Lake that have been intruded by Tertiary flow volcanics and Mesozoic granites, granodiorites, and quartz diorites. There is minor faulting in the basins, and buried faults lie along the lake edge. The major range-front fault is the northwest-trending Honey Lake Fault.

Deep circulation in the Honey Lake fault and an aquifer in valley-fill deposits make up the geothermal resource.

The geothermal reservoir at this site is a volcano-tectonic model, which makes it more susceptible to subsidence. The fluid is either a vapor-dominated or liquid-dominated system that is geothermally pressured, making it more or less susceptible to subsidence. Hydrocompaction is not likely to be a problem here. Other factors influencing subsidence are normal faulting, which increases susceptibility; and some interbedded volcanics in the valley fill which may make it less susceptible.

In summary, available information on the geologic and reservoir conditions indicates that Site No. 3 is moderate to moderately high in potential susceptibility to subsidence (Table 35).

Sites Nos. 6 and 13 are located in Modoc and Lassen Counties, in the Basin and Range geologic province. The resources are springs in Tertiary volcanic rock flows, minor pyroclastic deposits, and mud flow deposits. Site No. 6 is in a northwest-trending fault zone. Both sites are in volcanic basins in the Surprise Valley region. The many broad valleys of this province represent down-dropped fault blocks separated from each other by mountain ranges and subsequently filled with valley-fill deposits. The hot springs found in this region are commonly associated with range front faulting. The major range front fault is the north-trending Surprise Valley Fault.

Deep circulation in the Surprise Valley fault zone, with a possible magmatic source at depth, provides the geothermal resource. Surprise Valley is a high-temperature system, with springs ranging from 21° to 86° C (Muffler 1979).

The geothermal reservoirs at these sites are volcano-tectonic models, which make them more susceptible to subsidence. The fluid is either a vapor-dominated or liquid-dominated system that is geothermally pressured, which makes it more or less susceptible to subsidence. Hydrocompaction is not likely to be a problem here. Other factors influencing subsidence are type of faulting (normal), which increases it, and interbedded volcanics in the valley fill deposits, which may decrease it.

In summary, available information on the geologic and reservoir conditions indicates that these sites are moderate to moderately high in potential susceptibility to subsidence (Table 35).

Oregon

Eight geothermal use areas were identified in Oregon. All of these sites are within the Basin and Range physiographic province of southern Oregon. The area is characterized by generally north-trending narrow ridges separated by various sizes of basins. In addition to block faulting, some tilting has occurred, which causes many of the ranges to be steep on one side and gently sloped on the other. Numerous hot springs are found throughout the region as the faults provide conduits for surface expressions of geothermal resources. The faults provide for circulation of meteoric waters, so these systems are generally geothermal convection systems.

Sites Nos. 14, 16-17, and 19-21 are located in Klamath County in the Basin and Range geologic province. The geothermal resources are wells in basalt, andesite, pyroclastic rocks, and fluviatile and lacustrine volcanics. The basalts are interbedded with tuffs and laminated siltstones. The volcanism that produced these deposits is Pliocene and Pleistocene in age. Northwest-trending faults predominate. The Klamath River is southwest of this area, and some alluvium is present in the river valley.

These sites are within the Klamath Falls-N. Altamont-Pelican City Subarea of the Klamath and Klamath Hills Known Geothermal Resource Area (KGRA). The reservoir temperatures range from 15° to 95° C (Muffler 1979).

The geothermal reservoirs at these sites are in alluviated valleys in volcanic terrain, which makes them intermediate between volcanic and volcano-tectonic models. They are probably liquid-dominated systems that are geothermally pressured, which makes them susceptible to subsidence. Hydrocompaction is not likely to be a problem here. Other factors influencing subsidence are the interbedded basalts and the type of faulting (normal). The former lessens the potential for subsidence, and the latter increases it.

In summary, available information on the geologic and reservoir factors indicates that Sites Nos. 14, 16-17, and 19-21 are potentially moderately susceptible to subsidence (Table 35) (Geothermal Task Force 1980).

Sites Nos. 15 and 18 are located in Klamath County in the Basin and Range geologic province. The geologic conditions are similar to the previously discussed sites, except that the alluvial cover appears to be thicker.

These sites are within the Klamath Hills-Spring Lake Valley Subarea of the Klamath and Klamath Hills KGRA. The reservoir temperatures range from 15° to 95°C (Muffler 1979).

The geothermal reservoirs at these sites are in alluviated valleys in volcanic terrain, which makes them intermediate between volcanic and volcano-tectonic models. They are probably liquid-dominated systems that are geothermally pressured, which makes them susceptible to subsidence. Hydrocompaction is not likely to be a problem here. Other factors influencing subsidence are the interbedded basalts and the type of faulting (normal). The former lessens the potential for subsidence, and the latter increases it.

In summary, available information on the geologic and reservoir factors indicates that Sites Nos. 15 and 18 are potentially moderately susceptible to subsidence (Table 35) (Geothermal Task Force 1980).

SUMMARY

It appears that most of the sites could potentially experience subsidence if reinjection of effluent did not occur. The sites, ranked from least to most likely to experience subsidence, are listed in Table 36. None of the sites

Table 36. Susceptibility to subsidence.

Not Susceptible
(Favorable reservoir fluid phase and geologic factors)

- None

Low Susceptibility
(Favorable geologic factors and less desirable reservoir fluid phase)

- Adams (5), Idaho
- Blaine (6 and 7), Idaho
- Boise (8), Idaho

Moderate Susceptibility
Moderate geologic factors and less desirable reservoir fluid phase; or, favorable fluid phase and less desirable geology)

- Camas (9 and 10), Idaho
- Custer (21), Idaho
- Sanders (16 and 17), Montana
- Beaverhead (18 and 19), Montana
- Klamath 1 (14, 16, 17, 19, 20, and 21), Oregon
- Klamath 2 (15 and 18), Oregon
- Modoc 5 (13), California
- Nye (15-19), Nevada
- Washoe 5 (63-78), Nevada
- White Pine 1 (79 and 80), Nevada
- Socorro (18), New Mexico

High Susceptibility
(Both geologic factors and reservoir fluid phase less than desirable)

- Elmore (15), Idaho
- Gooding (16), Idaho
- Jefferson (2 and 3), Montana
- Lassen 1 (3), California
- Lassen 4 (6), California
- Catron 1 (9), New Mexico

appeared to be without any potential for subsidence. The sites with the best reservoir conditions (vapor-dominated) did not have correspondingly favorable geologic factors (crystalline igneous or metamorphic rock type). In ranking the sites it was assumed that favorable geologic factors would take precedence if the reservoir conditions were not favorable.

The most ideal site for surface disposal of effluent to create wetlands would have a vapor-dominated reservoir within thrust-faulted, unfractured, igneous or metamorphosed rock. If there are overlying sediments, they would be either indurated, cemented sands in a few thick beds, or interbedded with volcanic flows, welded tuffs, and shallow ash flows. The greater the overburden thickness, the better.

Sites that are less susceptible should probably be studied further to determine whether other environmental factors are compatible.

Sites that are moderately susceptible may be feasible if the predicted impacts and mitigations required are acceptable to the user.

Sites which are most susceptible might be impossible to utilize for effluent disposal to create wetlands.

POTENTIAL INTERFERENCE WITH GROUND WATER

INTRODUCTION

Surface disposal of geothermal effluents to wetlands has the potential for impact (both beneficial and detrimental) on ground water aquifers. A generic discussion of factors that control migration to and through the aquifer is necessary in order to define conditions that have the least potential for ground water contamination. General uses of aquifers, as well as potential impacts of contamination on use, are briefly discussed. Beneficial impacts of increased year-round supply to an aquifer are included in this section. Site-specific analysis is based on known or inferred geologic, hydrologic, and soil characteristics. Geothermal water quality at each site (Appendix A, Tables A1-A7) is compared with State water quality requirements to estimate the potential for contamination.

GENERIC FACTORS

Migration of Surface Water

Factors influencing the potential of surface water migration to and contamination of ground water aquifers can be divided into two general categories: (a) factors that affect contaminants during their migration to the aquifer, and (b) factors that affect contaminants after they enter the aquifer.

Factors that affect contaminants during their migration to the aquifer include:

Local topography. This factor can influence the proportion of surface discharges that will infiltrate to the aquifer. Generally, steeper slopes result in more overland flow (runoff) and less infiltration.

Evapotranspiration (ET). This occurs at the ground surface or in the upper portion of the zone of aeration. ET can serve as a concentrating mechanism, thereby increasing the concentrations of the contaminants.

Presence of aquicludes in the zone of aeration. Aquicludes such as clay lenses may inhibit the downward percolation of contaminants, resulting in perched water tables of the contaminant. The contaminant plume will flow laterally until: (a) it is discharged at the surface; or, (b) it encounters the limits of the aquiclude and percolates downward to the main water table.

Leaching of minerals in the zone of aeration. An increase in the amount of water infiltrating through the zone of aeration can result in increased leaching of the zone. Depending on the chemistry of the infiltrating surface discharges, the water may dissolve certain minerals, resulting in a significant change in its chemical character.

Physical characteristics of the zone of aeration. This factor is of primary importance, for it greatly influences the attenuation of contaminants before they reach the water table. The more pertinent characteristics are:

- Thickness (i.e., depth to water table). Attenuation will generally be more complete when the unsaturated zone is relatively thick. Thick zones provide more opportunity for attenuation via chemical reactions and sorption on mineral surfaces. Water tables are generally deeper in drier climates and coarser materials.

- Composition. Clays have the greatest capacity to sorb contaminants, while coarse materials such as gravels have very little capacity.

- Permeability. This influences the rate at which the contaminants will percolate. Low permeability allows more time for attenuation. Materials with high permeabilities have low sorption capacities. High permeability due to intensive fracturing or solutional openings may result in conduit flow and essentially no attenuation of the contaminant.

- Soils. Soil makes up the uppermost part of the zone of aeration. Its thickness, composition, and permeability can influence contaminants as described above. Indurated iron oxide or carbonate horizons may reduce permeabilities and cause near-surface perched water tables to form. The alluvial B2 horizon accumulates clays and organic matter (humus) having high sorption capacities.

Factors that affect contaminants upon entering the aquifer include:

Aquifer characteristics. This factor is very important because it determines the attenuation of contaminants within the aquifer. The most important characteristics are:

- Composition. Aquifers containing fine-grained material (such as clay) have the greatest capacity for sorption. To be most effective, the clay should form the matrix of a coarser material--and not be present as distinct clay layers.

- Permeability. Low permeability will generally correspond to high sorption in clastic sediments and rocks. Low permeabilities may also allow more time for the dilution of the contaminant and for modifying chemical reactions to occur. Aquifers that are highly transmissive allow little attenuation of contaminants, especially when most of their permeability is due to secondary porosity (fracturing and solutional openings).

- Flow rate. The flow rate of ground water will affect the size and shape of the contaminant plume. It is directly proportional to the permeability of the aquifer and its hydraulic gradient. If the contaminant is percolating to the aquifer at a steady rate, its immediate dilution upon entering the ground water will be affected by the flow rate. While high flow rates may increase attenuation due to dilution, attenuation of the contaminant by sorption will probably be very low in these situations.

Natural chemical character of the ground water. Surface discharges that migrate to ground water aquifers may not always result in contamination of the ground water. Many chemical constituents may occur naturally at relatively high concentrations in pristine ground waters. These discharges would not be considered contaminants if the migration of surface discharges does not actually degrade the condition of the in situ water.

Topography. This factor can greatly influence the pathway of the contaminant's plume through the aquifer, and therefore its residence time within the aquifer. Uplands are generally recharge areas, so contaminants entering here may travel relatively deep and far in the aquifer system. However, contaminants infiltrating in discharge areas (often valleys) may have very short pathways through the aquifer before they are discharged to springs or streams. The topographic factor can be quantified through the use of such parameters as stream density and proximity to effluent rivers.

Topography is a major determinant in the development of local and regional ground water flow patterns. Pronounced local relief will result in a predominance of relatively small, local flow systems. Areas with little relief often exhibit larger regional flow patterns. Low-relief areas may have aquifers that are very susceptible to widespread contamination.

Structural geology. Certain structural features can greatly influence the pathway of contaminants through the aquifer system. These features include:

- Faults. Brecciated fault zones may provide highly transmissive pathways for contaminants and provide little opportunity for attenuation.

- Joints and fractures. Fractures can influence contaminants in a similar manner as faults. Joints and fractures can produce anisotropic permeability in aquifers and therefore influence the direction of ground water flow.

- Dipping sedimentary beds. Infiltration of surface water discharges at the outcrop areas of dipping beds can result in contamination of confined (artesian) aquifers. At these recharge areas, contaminants enter the aquifer under water table conditions. The contaminant plume can then travel down-gradient until confined conditions are encountered. Leakage of contaminants may then occur to adjacent confined or water table aquifers.

Ground water flows from aquifers with higher head to those with lower head. For example, contaminants in a water table aquifer may migrate to a deeper artesian aquifer if the artesian head is below the water table surface. Conversely, if the artesian head is above the water table elevation, the contaminants cannot migrate to the artesian aquifer. The volume of leakage is directly proportional to the head difference between the aquifers and the permeability of confining beds.

Uses of Ground Water Aquifers

Ground water aquifers can be used for the following:

- Water supply.

- Storage of excess surface water for future use (artificial recharge).
- Storage of excess industrial heat/cold for future use.
- Waste storage or disposal.
- Heat supply (geothermal or ground water heat pump).

Ground water usage can be divided into two categories--potable and nonpotable. Contamination of any potable water supply could have detrimental effects on domestic water supply, livestock water supply, or base flow for perennial streams. Impacts of contamination possibly would not be as drastic on nonpotable usage.

Prevention of Migration

If the potential for contamination of the ground water aquifer is high, prevention of infiltration at the surface is possible by the application of materials of an impermeable nature to the ground surface. Natural substances, such as clay, can be used because they have extremely low permeabilities, although high porosities. In some situations, depending on soil suitability at a given site, existing soils may be sufficiently compacted to decrease their permeability. Synthetic materials such as concrete, asphalt, rubber, and plastic compounds may be used. Cost and durability (length of wetlands life) must be examined when considering the use of a natural or artificial liner to prevent percolation. Clay liner expenses are approximately $2,000-10,000 per acre. These can be expected to last indefinitely with little to no maintenance. The only cost involved for compaction is the rental of equipment and some degree of earthwork, which needs to be added to the cost of all other liners. Synthetic materials are considerably more expensive; asphalt, rubber, and plastic compounds average $4,000 to $52,000 per acre and exhibit similar life expectancies. All lining materials are subject to stress if harvesting of vegetation from the marsh is necessary.

The contaminants may be controlled by several methods after reaching the aquifer. Trenches or canals may be useful for intercepting the contaminants if the aquifer is thin and the water table is near the surface. This method may be of use when a local perched water table is present. Drainage tile may be useful in similar situations.

A properly designed well or well field could be used to intercept the contaminant plume and return it to the surface, possibly setting up a "closed system" where the contaminating waters are continually recirculated in the local area. This could be done in two ways:

- Intercepting the plume down-gradient.
- Changing the gradient at the site of infiltration--A pumping well's cone of depression may "capture" all of the contaminant plume and prevent it from migrating away from the site.

Depending on the contaminants present, harvesting of vegetative material might be necessary to prevent concentration of contaminants in a closed system. Table 37 compares costs of prevention methods and interception methods for controlling contamination of the aquifer.

Table 37. Comparison of costs for the prevention of downward surface water migration and interception of contaminants in aquifer.

		Method				
		Prevention ($/ac)		Interception		
Costs	Compaction	Clay	Synthetics	Excavation	Drainage tile	Wells
Initial	$1,000	$2,000-$10,000	$4,300-$52,000	$800-$1,200/ac	$1,200-$2,400/ac	$10,000-$100,000/well
O/M	-	-	-	$2/ft^3/yr		1,500/yr
Life span	Indefinite	Indefinite	10-50 yrs	Indefinite	60-80 yrs	30 yr

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METHODS

Soils

Soils information was obtained from the U.S. Soil Conservation Service (SCS). Some of the information existed in published soil surveys, but most of it was obtained through phone conversations with representatives of SCS county field offices. They were able to provide the names of established soils series at a given township, range, and section within their county.

The SCS soil series descriptions are perhaps the best source of site-specific data. Each soil series is described in a standardized format that contains information directly applicable to site-specific hydrologic factors.

The soil series interpretation section (not available for all series) contains two general types of information: (a) estimated soil properties for each identified soil horizon, and (b) ratings in terms of limitations and suitability for a number of potential uses of the soil. Included in the ratings section is a determination of wildlife habitat suitability for wetlands plants and animals. (Although this rating is obviously useful and relevant, it is not by itself an indication of the potential for interference with ground waters.)

Information on the following soil properties was important in evaluating a site's potential for ground water contamination.

- Clay (percentage).
- Permeability.
- Water table (depth, type).
- Cemented pan (depth).
- Bedrock (depth).

Soil information for several sites was unavailable. These sites either had not yet been mapped or were located on private landholdings, Indian land, or U.S. Forest Service land. Table H-1 (Appendix H) summarizes the sources used for gathering soils data. Table H-2 (Appendix H) presents the soil data obtained from the SCS soil series descriptions.

Geology

Information on the geology of the potential wetlands sites was obtained primarily from regional geologic maps published by various State agencies. None of the sites were covered by the small-scale geologic quadrangles of the U.S. Geological Survey (USGS). At a few sites geologic information from the regional maps was supplemented by other information from published sources.

Table H-3 (Appendix H) presents the geologic information for sites deemed feasible in Section 8. In this table, known geology refers to information that was derived directly from the geologic maps, while inferred geology refers to those aspects of site-specific geology that were extrapolated from topographic quadrangles.

The geohydrologic characterization for each site was derived by synthesizing the available soil, geologic, and hydrologic information. Many data were lacking, but certain aspects of site-specific geohydrology could be deduced simply by interpreting the available data in light of general hydrologic principles.

Limitations

Soils data were available by section (approximately 640 acres) of a particular township and range. Several soil types can exist in a relatively small topographic area. Without the aid of detailed mapping, the exact location of a suitable soil cannot be determined. Soil information obtained is limited to the section of the reported geothermal resource, while a preferable site for a wetlands development may exist up to 3 miles from the source of effluent.

Comparisons of effluent quality and State water quality requirements are based on available, existing information, no matter how limited. Often, major data gaps occur for a particular geothermal resource site (e.g., no metals data or fluoride data lacking). Either the particular constituents were not present at that site or measurements were not made to see whether a particular constituent was present (the latter is more likely true). Aside from major data gaps at geothermal sites, States have not established water quality requirements for most constituents that occur in geothermal effluents. State water quality requirements are listed in Table 5, page 26.

Regional geologic maps vary in scale from 1:1,000,000 to 1:1,500,000; therefore, resolution of surface geology is not fine. However, geologic information obtained from the literature is used in conjunction with topographic quadangles to formulate site-specific geology.

RESULTS

Idaho

Site No. 5, located in the Weiser River drainage basin, is primarily a recharge area for the regional basalt aquifer system. The permeability of the basalt is high, but only in porous zones between individual basalt flows. Meteoric water infiltrates the thin (10-20 inches), slowly permeable Tica soil and enters the ground water under water table conditions. Confined conditions may be encountered as ground water flows in the general direction of the original lava flow (Freeze and Cherry 1979). Although local relief appears great and the topography well defined, local ground water flow patterns may not develop because of the anisotropic (directional) permeability of the basalt aquifers.

Basalt aquifers are the most important ground water source for the Council area, which is about 8 miles west of the site location. Their wells are generally 80 to 180 feet deep and may yield up to several hundred gallons per minute (Walker and Sisco 1964).

No apparent conflict exists between the effluent quality of the geothermal source at this site and State water quality requirements.

An alluvial aquifer is present at Site No. 6 located in the Warm Springs Creek Valley. The creek is a perennial stream fed by intermittent tributaries that flow from the surrounding uplands. The uplands are composed of thrusted deep marine to transitional deposits, rocks that generally are not permeable enough to be considered good aquifers. Ground water flow in these types of rocks should be primarily downslope to the Warm Springs Valley. Ground water movement in the alluvium of the valley probably has two directional components: one toward the creek, the other downstream.

The soils present in the valley have permeabilities varying from moderately rapid to moderately slow. The water table seasonally comes to within 3 feet of the surface in some areas of the valley. For most of the valley floor, however, it probably ranges from 8 to 20 feet below the ground surface.

No apparent conflict exists between the effluent quality of the geothermal source at Site No. 6 and State water quality requirements.

The hydrologic characterization of Site No. 7 is quite similar to that of Idaho Site No. 6. One important difference is that some mixed volcanic lithologies occur in the upland regions, in addition to the thrusted marine sediments that predominate. Some of the volcanic rocks may have permeable interflow zones that transmit water much more readily than marine sedimentary rocks. The alluvial aquifers of the Trail Creek and the Big Wood River valleys should have good permeability. The valley floors have a fair amount of relief, so depth to the water table may vary considerably in the area. It is probably about 20 to 40 feet deep in much of the valley. As in Site No. 6, ground water movement is primarily downstream and toward the river channel.

No apparent conflict exists between the effluent quality of the geothermal source at Site No. 7 and State water quality requirements.

Intrusive igneous rock characterizes Site No. 8. Its greatest permeability is near the surface, where fracturing and weathering have greatly increased porosity; permeability decreases with depth. Infiltrating meteoric water enters the water table in this permeable zone and flows toward the South Fork Payette River Valley. The ground water may eventually flow into the colluvium and talus deposits of the valley. These sediments are largely unsorted, but they possess a high permeability because of their overall coarse nature. The ground water in the colluvium and talus will flow predominantly northwest, toward the basin-filling deposits of Garden Valley. These deposits form a more extensive alluvial aquifer that may be considerably less permeable than the upstream colluvium and talus deposits. The depth to the water table is probably in the 20- to 40-foot range. It appears likely that deeper, confined aquifers are also present in the Garden Valley alluvial deposits.

No apparent conflict exists between the effluent quality of the geothermal source at Site No. 8 and State water quality requirements.

Idaho Site No. 9 is located on the Camas Prairie, a structural depression that has been filled with alluvial and lacustrine (lake) sediments. Walton (1962) described the geohydrology of the prairie in detail. He observed that unconsolidated sediments average about 450 feet thick and generally become less coarse to the south. A thick clay layer is generally present from a depth of about 120 to 210 feet. Above this clay are alternating beds of sand, silty sand, silt, and clay, a sequence of sediments that are only moderately permeable. Water table conditions are usually present in these sediments to a depth of about 40 feet, while the depth to the water table may vary between 1 and 20 feet. Below the thick clay are two artesian aquifers that are generally more permeable and yield water in amounts sufficient for irrigation and other large-scale uses. Over most of the prairie, the artesian pressure of the confined aquifers results in wells that flow at ground level. The ground water movement in the confined aquifers is away from the uplands and toward an eastward trending trough that roughly aligns with Camas Creek. Large amounts of ground water from these deep aquifers appear to leak upward into the shallow, unconfined aquifer.

Site No. 9 is bounded to the north by uplands composed of intrusive igneous rocks. These rocks have some permeability due to fracturing, but ground water movement is generally very slow. Wells in these rocks yield sufficient water for domestic and stock uses. Runoff from uplands flows across Site No. 9 in Lansing Creek and Corral Creek. Both creeks probably lose some water to the shallow alluvial aquifer, because water level data indicate that the water table is from 7 to 20 feet deep in this area (Walton 1962; U.S. Geological Survey 1972a). However, the soil information indicates that, seasonally, it may be within 2 or 3 feet of the surface in some areas. Ground water movement in the aquifer is primarily to the southeast, toward Camas Creek.

State requirements are not set for any of the constituents that occur in the geothermal resource fluid at Site No. 9.

Site No. 10 is located near the confluence of Camas and Corral Creek, on the Camas Prairie. The geohydrology of the prairie aquifers was described in the section on Idaho Site No. 9. At Site No. 10, the aquifers are composed of generally finer sediments and the medial clay layer is somewhat thinner. The aquifers are barely present south of Camas Creek, as most of this area is uplands composed of volcanic rocks (mixed silicic and basaltic flows and ejecta). Although great yields are obtained from basalt aquifers in the Camas Prairie region, the basalt at Site No. 10 probably receives very little recharge from precipitation. This is because the overlying Polecreek and Manard soils are only very slowly permeable.

The alluvial aquifers at Site No. 10 probably have a large proportion of fine-grained lacustrine sediments. The water table of the upper aquifer is very close to the ground surface, especially in areas close to the creeks. The potentiometric levels of the deeper artesian aquifers are above the ground surface (Walton 1962). Ground water movement is primarily toward Camas Creek, an effluent (gaining) stream.

No State water quality requirements are set for any of the constituents that occur in the geothermal effluent at Site No. 10.

Site No. 21 is located in the steep valley of the Salmon River. Very little alluvium is present in the river valley, so the underlying intrusive igneous rock is the best (and only) aquifer at the site. Yields from wells generally should not be very great, since the igneous bedrock exhibits decreased permeability with depth. Ground water movement, occurring in fractures and joints, is slow and controlled primarily by the local topography. The gradient of flow is toward the Snake River.

Site No. 21 exceeds State criteria set for fluoride levels, but meets all other State criteria.

Montana

Available information indicates that Site No. 16 is underlain by silty glacial lake deposits that are very poor aquifer materials. Since the climate is semiarid, the water table in these sediments is probably moderately deep. The perennial Hot Springs Creek flows across the section, but it is most likely perched on the "tight" Allentine and Round Butte soils and, therefore, is not hydraulically connected to the underlying silty aquifer. The site location may be a recharge area, consequently any creek water or precipitation that percolates through the soil and down to the water table will probably flow to the east. Since there is a lack of well-defined topography to the east, the flow patterns in the aquifer will probably be relatively shallow and regional in extent. The ground water flow rate will be slow because of the low permeability of the glacial sediments.

No apparent conflict exists between the effluent quality of the geothermal source at Site No. 16 and State water quality requirements. Montana sets criteria on few constituents found in water. All sites in Montana meet water quality standards for constituents where levels are defined.

The alluvial deposits in the Clark Fork Valley are the major aquifer in Site No. 17. Although permeabilities are likely to vary greatly with the proportion of sand and gravel present, the average permeability of the aquifer is relatively narrow and, therefore, never very far from the river. As a result the elevation of the water table will be close to the elevation of the water surface of the river. This implies that the water table will be only a few feet deep in the floodplain area. The river is probably effluent (gaining), except during some of its higher flood stages. Therefore, ground water in the alluvium should flow downstream, but into the river relatively quickly.

The surrounding uplands of this area are composed of less-permeable Precambrian intrusive igneous and argillaceous rocks. The permeability of these rocks will increase with depth as weathered rock gradually changes to unaltered bedrock. Surface runoff, ground water, and interflow will provide recharge to the alluvial aquifer.

No apparent conflict exists between the effluent quality of the geothermal source at Site No. 17 and State water quality requirements.

Intrusive igneous rocks form the bedrock at Site No. 18. This type of rock has some potential as an aquifer, especially at relatively shallow depths where secondary porosity is created by joints, fractures, and weathering. This site has fairly well-defined topography, so ground water flow patterns are likely to be deep but local. The overall gradient of flow should be to the southwest. Depth to the water table is likely to be quite variable and sometimes near the surface, depending on the local topography.

Glacial drift and alluvium occur south of the site, but it does not appear likely that ground water from Site No. 18 could flow into these deposits before discharging into local creeks.

No apparent conflict exists between the effluent quality of the geothermal source at Site No. 18 and State water quality requirements.

Geologic information indicates that Site No. 19 is underlain by materials possessing good aquifer properties. The northern half of the site has tertiary clastic sedimentary rocks that form a relatively steep upland region. These uplands are probably a recharge area for the sedimentary aquifers. Infiltrating meteoric water will enter the aquifer system under water table conditions, but semiconfined or confined conditions will soon be encountered in the inclined sedimentary beds. The water table is probably of moderate depth in this subhumid climate.

The low-lying areas of Site No. 19 are composed of alluvial valley fill deposits that should be very permeable. On some of the lower terraces along streams, the water table in the alluvium may seasonally be within a few feet of the ground surface. The Slocum and Bridges soils of this area are moderately permeable, so perched water tables probably do not occur. The ground water flow gradient is predominantly to the west, toward Big Hole River.

No apparent conflict exists between effluent quality of the geothermal source at Site No. 19 and State water quality requirements.

Nevada

Sites Nos. 15-19 are underlain by alluvial fan and playa deposits. The fan deposits have very high permeability, but this aquifer characteristic decreases to the east as the sediment becomes finer and the playa deposits are encountered. The soils that have developed on these materials exhibit a similar trend of decreased permeabilities to the east. Surface runoff from the Toiyabe Range infiltrates rapidly through the Wrango soils that overlie the coarser fan deposits occurring in Section 7. As the slope of the alluvial fan flattens abruptly near the Section 7/Section 8 boundary, the water table comes very close to the ground surface. Many springs occur in this ground water discharge area; some are hot springs, indicating that the ground water flows of the alluvial aquifer are augmented by water flow from the underlying tertiary volcanic rocks. The surface runoff from some of these springs has created a marsh area to the east that appears to be perched on the nearly impermeable Lahontan soil. Although the water table is probably still relatively close to the surface at this location, it undoubtedly gradually becomes deeper to the east. It may eventually become moderately deep, as is typical of a semiarid climate.

No apparent conflict exists between the effluent quality of the geothermal source at Sites Nos. 15-19 and State water quality requirements. All geothermal sources in this geographic area are high in fluoride, but Nevada does not regulate fluoride content in State waters.

The alluvial deposits in the vicinity of Steamboat Creek are the major aquifer of Sites Nos. 63-68. This aquifer probably becomes thicker, but somewhat less permeable as playa deposits are encountered to the north. It may not be very thick where it is closest to the site locations, because rock outcrops occur over much of the area just west of the creek. Near the site locations, Steamboat Creek may be perched on the silica-cemented duripan of the Vamp soil. However, at least some portions of the creek appear to be aligned on a fault, thus it is possible that upwelling spring waters are contributing to the creek's base flow.

The semiarid climate at these sites implies that the water table in the alluvium may be moderately deep, but the influence of thermal spring waters from the intrusive igneous rocks, plus local thinning of the aquifer, may result in a somewhat higher water table than expected. Ground water flow should be predominantly to the north, away from the igneous uplands. Depth to the water table may also increase in this direction.

No apparent conflict exists between the effluent quality of the geothermal source at Sites Nos. 63-68 and State water quality requirements.

Sites Nos. 79-80 are located in the Steptol Valley, an area that is topographically closed and hydrologically undrained (Snyder 1963). The alluvium and playa deposits of this area result in an aquifer that is likely to have variable permeability. The less-permeable playa sediments may act as aquicludes by partially confining ground water occurring in the alluvium. Published information indicates that the water table probably varies from 5 to 20 feet below the ground surface in this area (Clark and Riddell 1920; Snyder 1963; U.S. Geological Survey 1972b). It is shallowest at the lower elevations along Duck Creek. The ground water gradient is to the east, toward the creek. Other streams near the site are intermittent; some disappear before reaching Duck Creek, indicating that soil permeabilities are probably quite high.

All State water quality requirements are met by the geothermal resource at Site Nos. 79-80.

New Mexico

Site No. 18 appears to be near the hinge line (i.e., recharge area/discharge area boundary) of the volcanic-alluvial aquifer system that is present in the Rio Grande River. Meteoric water infiltration in the volcanic uplands flows predominantly to the east, toward the Rio Grande River. The alluvial fan deposits (gravel facies) that begin at the edge of these uplands are probably poorly sorted, but good aquifer material. Overall, the water table is likely to be moderately deep, typical of an arid climate. Ephemeral perched water tables may be present in some portions of the alluvial fan deposits due to caliche formation in the C horizon of soils of the Nichel series (Hunt 1978). The pond in the northwest portion of the section is probably perched as a result of such a cemented horizon. The caliche is probably not widespread, since water from the two springs at the foot of the uplands does not remain at the ground surface very long before infiltrating into the alluvium.

The geothermal resource from Site No. 18 meets all State water quality requirements.

Northern California

Site No. 13 appears to be part of the broad recharge area for an extensive basalt aquifer system. Upland areas exhibit drainage patterns developed by intermittent streams. The high permeability of the surface rocks (volcanic flow rocks), along with a probable thin and well-drained soil cover, results in rapid infiltration of meteoric water and a nearly complete lack of surface drainage in the lowland areas. At the edge of the uplands, hot springs upwell along the fault zone, but their water soon percolates down to the water table aquifer. Ground water flow gradients are probably to the south and southwest. Recharge water at Site No. 13 may, in fact, discharge at the springs that feed Big Lake and Norr Pond about 7 miles south. Flow rates are likely to be high, as the ground water flows predominantly in the highly permeable zones between individual lava flows.

The geothermal effluent at Site No. 13 does not meet State water quality requirements because the levels of total dissolved solids, boron, and sulfate are beyond the limits set. Treatment capacity exhibited by wetlands might reduce the concentration of these constituents to acceptable levels.

Oregon

The highly permeable, waterlaid volcanic rocks at Sites Nos. 14, 17, and 19 are a major aquifer in some parts of the Klamath Basin. Much of the permeability may be due to fracturing along fault zones rather than to the porous interflow zones that commonly occur in basalt flows (Sammel 1980). The eroded bedrock surface is covered by the thin and moderately permeable Stuhel soil. Infiltrating precipitation will recharge the water table aquifer, which is probably quite deep in this area. Ground water flow is primarily to the southwest, toward Lake Ewauna, but exact flow patterns are difficult to predict since some compartmentation of the aquifer may have resulted from faulting.

Geothermal effluents at Sites Nos. 14, 17, and 19 meet most of the State water quality criteria. Levels of boron and sulfate exceed state limits, but treatment by wetlands should lower concentrations of these constituents before they reach the aquifer.

Sites Nos. 15 and 18 encompasses two distinct topographic regions: the Klamath Hills and the Lower Klamath Lake plain. The Klamath Hills are a recharge area for the highly productive volcanic aquifers of the region. The drained lowlands of Lower Klamath Lake are alluvial sediments containing some stratified lacustrine deposits. The deposits do not have an overall high permeability, but layers of coarser sediments do occur. The water table is within a few feet of ground level and its surface is probably very flat. The slight gradient that does exist may be northwest toward the Klamath River. Since the water table is so shallow, a large amount of ground water discharge probably occurs by evapotranspiration.

Geothermal effluents at Sites Nos. 15 and 18 meet most of the State water quality criteria. Levels of boron and sulfate exceed state limits, but treatment by wetlands should lower concentrations of these constituents before they reach the aquifer.

Waterlaid volcanic rocks are present in the northeast half of Sites Nos. 16 and 21. The hydrogeology of the volcanics was described in the section on Oregon Site Nos. 14, 17, and 19. The remaining portion of the site area is underlain by alluvial deposits of varying permeability. Wells in the alluvium yield ground water in much smaller quantities than do wells in the volcanic rocks. The water table in the alluvium is close to the ground surface, perhaps only 5 to 15 feet deep (Sammel 1980). Soil data indicate that seasonally it may come within 1 or 2 feet of the surface in the low-lying areas close to Lake Ewauna. The Hanley and Hosley soils have indurated duripans, so a perched water table may be present in the areas where these soils occur. Ground water movement should be predominantly south or southwest, toward Lake Ewauna. Deeper confined aquifers near the lake may have some leakage upward to the unconfined aquifer (Sammels 1980).

Geothermal effluents at Sites Nos. 16 and 21 meet most of the State water quality criteria. Levels of boron and sulfate exceed State limits, but treatment by wetlands should lower concentrations of these constituents before they reach the aquifer.

The hydrologic characterization of Site No. 20 is very similar to that of Oregon Sites Nos. 14, 17, and 19. The primary difference is the occurrence of basalt and andesite flows, rock units that are major aquifers in the Klamath Basin area. Site No. 20 is a recharge area for these aquifers as well as for the waterlaid volcanic rock aquifers.

Geothermal effluents at Site No. 20 meet most of the State water quality criteria. Levels of boron and sulfate exceed state limits, but treatment by wetlands should lower concentrations of these constituents before they reach the aquifer.

Final Evaluation

A final evaluation of the potential wetlands sites was made using soil, geologic, and geohydrologic data presented in the preceding sections. The evaluation is subjective in nature because the quantity and quality of background information vary with each site. It is this lack of internal consistency in site-specific data that precludes the use of a standardized evaluation system such as that of LeGrande (1980).

An evaluation of the sites is presented in Table 38. At each site the evaluation is based on a number of factors that affect potential contamination of an aquifer. Only the most critical factors discussed in the generic evaluation section were used. Each factor's influence at a site is rated on a scale ranging from highly favorable to highly unfavorable. In some instances, the rating is given as a range in an attempt to reflect the impact of variable conditions at a site. Table 39 presents a final comprehensive rating for each of the sites deemed feasible.

Table 38. Site-specific evaluation for potential contamination of ground water.

	Factors affecting potential contamination								
	Soil		Zone of aeration			Aquifer			Leakage to other Aquifers[b]
State/site no.	Permeability	Composition	Thickness	Permeability	Composition	Permeability	Composition	Extent[a]	
CA[c] 13	ND[d]	ND	Low[e]	Very high[f]	Very high	Very high	Very high	Moderate[g]	Moderate
ID[h] 5	Low	Low	Low	Very high	Very high	Very high	Very high	High[i]	Moderate
ID 6	Moderate	Moderate	High	Moderate	Moderate	Moderate	Moderate	Low	Low
ID 7	Moderate	Moderate	Moderate	Moderate	Low	Moderate	Low	Moderate	Moderate
ID 8	High	High	Moderate	High	Moderate	High	Moderate	Moderate	High
ID 9	Moderate	Moderate	Moderate	High	Moderate	Moderate	Moderate	Moderate	Low
ID 10	Very low	Low	Very high	Low	Low	Low	Low	Very low	Very low
ID 21	ND	ND	Moderate	Moderate	Moderate	Low	Very high	Low	Very low
MT[j] 16	Very low	Low	Low	Low	Low	Low	Very low	High	Low
MT 17	ND	ND	High	Moderate	High	High	High	Low	Very low
MT 18	ND	ND	Moderate	Moderate	Moderate	Low	Very high	Low	Moderate
MT 19	Moderate	Moderate	Low	High	High	High	High	Moderate	Moderate
NV[k] 15-19	Low	Moderate	Moderate	Moderate	Low	Low	Low	High	Low
NV 63-68	Moderate	Moderate	Low	Moderate	Moderate	Moderate		High	Low
NV 79, 80	ND	ND	Low	Moderate	Moderate	Moderate	Moderate	Low	Low
NM[l] 18	Moderate	Moderate	Low	High	High	High	Moderate	Moderate	Low
OR[m] 14,17,19,20	High	Moderate	Low	Very high	Very high	Very high	Very high	High	High
OR 15, 18	Low	Moderate	Very high	Low	Low	Low	Low	Moderate	Low
OR 16, 21	Low	Moderate	Very high	Moderate	Moderate	Moderate	Moderate	Moderate	Low

[a] Extent--Refers to the predicted extent of contamination within the aquifer.

[b] Leakage to other aquifers--Refers to the potential for the contaminant to migrate from the primary aquifer to another one, perhaps deeper (confined) or farther away.

[c] CA = California.

[d] ND = No data.

[e] = Moderate potential for contamination of ground water.

[f] = Very high potential for contamination of ground water.

[g] = Moderate potential for contamination of ground water.

[h] ID = Idaho.

[i] = High potential for contamination of ground water.

[j] MT = Montana.

[k] NV = Nevada.

[l] NM = New Mexico.

[m] OR = Oregon.

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Table 39. Potential for contamination of ground water at geothermal sites (not necessarily geographic areas).

Low

- Sanders (16), Montana
- Nye (15-19), Nevada
- Camas (9 and 10), Idaho
- Washoe 5 (63-78), Nevada
- Klamath 2 (15 and 18), Oregon
- Blaine (6 and 7), Idaho

Moderate

- Custer (21), Idaho
- Beaverhead (18 and 19), Montana
- White Pine 1 (79 and 80), Nevada
- Klamath 1 (16 and 21), Oregon

High

- Modoc 5 (13), California
- Adams (5), Idaho
- Boise (8), Idaho
- Sanders (17), Montana
- Socorro (18), New Mexico
- Klamath 1 (14, 17, 19, and 20), Oregon

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[a] Low potential for contamination indicates a favorable site for wetlands development.

CONTAINMENT AREA

INTRODUCTION

Each potential site for wetlands development must have a sufficient area available for disposal of the geothermal effluent to be discharged. The containment area must accommodate all or a significant fraction of the expected geothermal effluent without overland flow to surface waters. In order to determine whether sufficient area exists at any site, it is necessary to define the optimum size for wetlands development. Optimum size is determined by many physical factors, as well as economic considerations and time period of usability. The optimum location of the wetlands, in relation to predicted waterfowl usage, must also be examined.

GENERIC CONSIDERATIONS

Generic considerations for wetlands development include:

- Minimum size (acreage).
- Flow requirements.
- Application rate/retention time.
- Life span of wetland (soil suitability).
- Surface ownership.
- Potential waterfowl usage.

One of the criteria to be defined initially is the minimum acreage needed to establish a wetlands. When considering the amount of time and expenditures involved in creating a wetlands, a reasonable minimum area would appear to be approximately 100 acres. This acreage would attract waterfowl but would not support a large breeding population. The optimum surface water to wetlands ratio of 1:2 would require approximately 35 acres in pond and 65 acres of marshes.

The volume of effluent needed to maintain 100 acres of wetlands is approximately 450 gallons per minute (gpm) (Jensen 1974). This is a minimum year-round water requirement and does not consider surface evaporation. The average evaporation rate on a year-round basis in the seven States considered in this study is between 1 and 5 gpm/ac. This is one of the most variable factors involved, as microclimatic changes, area relief, wind, and numerous other physical phenomena can drastically alter surface evaporation. Evapotranspiration from vegetation is too variable to predict.

In order to supply the volume of effluent necessary to maintain a wetlands, the rate of wastewater discharged from a geothermal facility needs to be examined. Rate of wastewater discharge is highly dependent on the potential use of the geothermal resource. In general, a small facility using geothermal effluent for space heating would discharge from 10 to 300 gpm. A large facility would expel 200 to 500 gpm. Industrial processes vary widely in the amount of geothermal fluids used. An average usage rate may be between 300 and 400 gpm, while a major user may reject fluid up to 800 gpm. Geothermal water usage associated with an electrical generating facility may produce a more constant flow rate under defined conditions. For example, a 25-MW generating facility using a 100° C resource would reject effluent at approximately 33,000 gpm.

A major industrial user or an electrical generating facility appears to have the most potential for supplying enough effluent to meet the demand for wetlands development.

At potential sites where discharge to surface water is allowed, a loading rate of up to 50 gpm/ac is feasible. It is anticipated, however, that discharge will not be allowed at most sites. The loading rate in this situation decreases to 10 gpm/ac with a projected retention time of between 2 and 7 days, depending on soil suitability (percolation rate).

The length of time that a site remains usable for effluent disposal depends on a great many factors. A major consideration is the length of time a geothermal facility is operable. Predicted life spans vary with the particular reservoir and no generalities can be stated. If the reservoir is constantly being supplied with effluent, the facility could continue indefinitely. Power companies count on an approximate 30-year life span.

After determining the length of time effluent will potentially be available, the next factors to consider are physical parameters of the soil. The question of how long a soil will retain properties needed for purification depends on the water treatment capacity of the wetlands vegetation, the initial quality of the effluent, and the properties of the soil itself. Examples from irrigation practices indicate that even poor quality water can be used continually without deleterious effects on the soil as long as constant flushing is maintained. The general topography of a potential site should be characterized by slopes of approximately 0 to 3 % (nothing over 8%) and mounded microrelief to provide wet and dry areas for habitat variability.

The potential for contamination of the ground water aquifer needs to be considered along with soil suitability. Table 39 rates the potential wetlands sites according to least potential for ground water contamination. That rating scale will be incorporated for the final consideration. Sites very close to populated areas should be avoided as these are unsuitable for wildlife use, and land prices would be excessive. Prime agricultural lands should also be avoided, but it is unlikely any such areas exist around the potential wetlands sites identified in this report.

Surface ownership of any potential site will ultimately control both the economic and the legal feasibility of any potential site. Reservation holdings, Forest Service holdings, and lands designated as state or national parks will present numerous time constraints to development of a wetlands even if a geothermal exploration use permit has already been granted. Private landholdings that could be purchased outright or State lands would be the best choice when considering location.

A major factor in selecting the location of a potential wetlands development is potential waterfowl usage. The most cost-effective site is one that lies in the path of migrating waterfowl, since there would appear to be a greater probability that more waterfowl would be exposed to a created wetlands along an existing migration route. Need for a created wetlands must also be considered; some areas may present a more critical need than others. For example, if large water bodies or wildlife refuges exist in an area, need for a wetlands would not be critical.

METHODS

All available information compiled in previous sections of this report was used to evaluate specific sites against generic factors. Sites mapped on USGS topographic maps were examined for area requirements and topography. To determine potential waterfowl usage, sites were located on maps showing duck and geese migration corridors, and were then ranked on the basis of densities of migrating waterfowl (Bellrose 1978).

Geographic areas recommended for more detailed investigations into their suitability for use as demonstration geothermal wetlands are the following.

- Idaho, Camas area, Sites Nos. 9 and 10.
- Montana, Beaverhead area, Sites Nos. 18 and 19.
- Nevada, Nye area, Sites Nos. 15-19.

Figure 6 shows the location of these sites in relation to all others.

Site visits and geotechnical investigations will be necessary to determine site-specific costs involved for wetlands creation. Costs will be linked to specific soils data and degree of sophistication desired for the wetlands development. Generic costs may be found in Section 6 of this report.

Mapped sites were examined for proximity to refuges and large water bodies with high potential for waterfowl contact.

Sites used in this evaluation are those deemed less susceptible and moderately susceptible from Table 36.

RESULTS

Table 40 summarizes the available information on potential site suitability. In Idaho, only Camas (Sites Nos. 9 and 10) has sufficient area available, suitable topographic and land use requirements, moderate soil suitability, and low potential for ground water contamination. This site has a low potential for waterfowl contact, but all other parameters used in the consideration for a wetlands demonstration site look good. All other sites in Idaho (Adams [5], Blaine [6] and [7], Boise [8], and Custer [21]) have poor topographic and land use suitability, a factor of enough consequence to eliminate them from further consideration as demonstration sites.

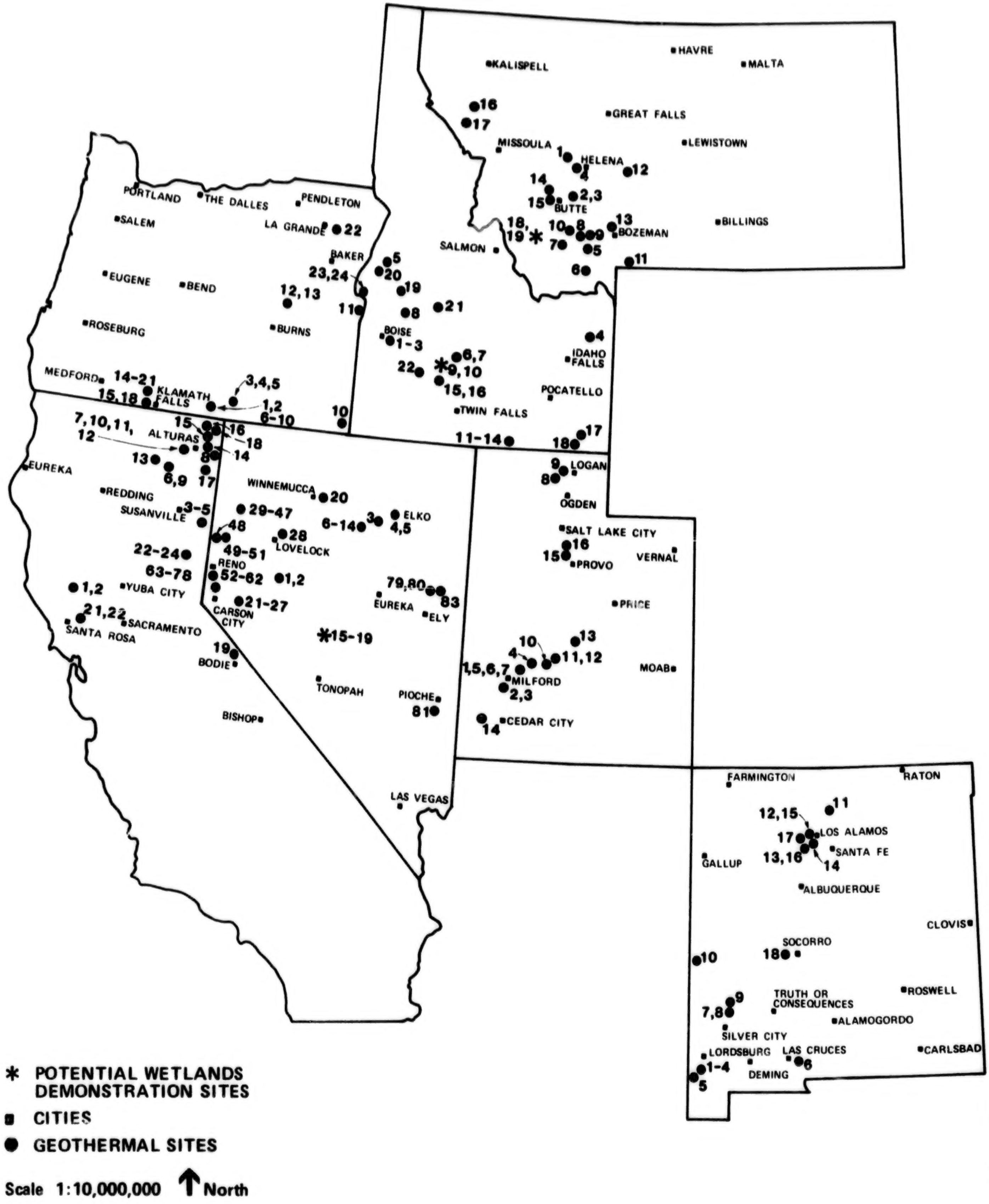

Figure 6. Location of potential geothermal wetlands demonstration sites.

Table 40. Summary information for site selection.

State	Area designation	Site no.	Projected use/ sufficient volume	Sufficient area available	Topographic and land use suitability[a]	Surface ownership or lessee	Potential for waterfowl contact	Soil suitability	Ground water contamination potential
Idaho	Adams	5	Space heat/ Probable	No	Poor	Forest Service	High	Suitable	High
	Blaine	6,7	Space heat/ Probable	Possible	Poor	Forest Service	Low	Moderate	Low
	Boise	8	Space heat/ Probable	No	Poor	Forest Service	High	Poor	High
	Camas	9,10	Space heat/ Probable	Yes	Suitable	Leased: R. L. Bullock	Low	Moderate	Low
	Custer	21	Space heat/ Probable	No	Poor	Forest Service	Moderate	-[b]	Moderate
Montana	Sanders	16,17	Space heat/ Probable	Yes	Suitable	Flathead Indian Reservation, Forest Service	High	Suitable (16)/-[b](17)	Low High
	Beaverhead	18,19	Space heat/ Probable	Yes	Suitable	Forest Service	High	-[b](18)/ Moderate (19)	Moderate
Nevada	Nye	15-19	Space heat Industrial/ Yes	Yes Existing marsh	Suitable	-[b]	Low	Suitable	Low
	Washoe 5	63-78	Space heat Electrical/ Yes	Possible		Leased: U.S. Geothermal	Moderate	Suitable	Low
	White Pine 1	79,80	Space heat/ Probable	Yes	Suitable	Leased: W. H. Hunt	Low	-[b]	Moderate
New Mexico	Socorro	18	Space heat/ Probable	Yes	Poor	Leased: Aminoil, Atlantic Richfield, Sunoco Energy	Moderate	Moderate	High
Northern California	Modoc 5	13	Industrial Electrical/ Yes	Yes	Suitable	Forest Service[c]	High	-[b]	High
Oregon	Klamath 1	14,16,17, 19,20,21	Space heat/ Probable	No	Poor	Klamath Falls City Limits	High	Poor/suitable (16, 21)	High/ Moderate (16, 21)
	Klamath 2	15,18	Space heat/ Probable	Yes	Poor	-	High	Suitable	Low

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[a] Rating takes into account proximity to populated areas and relief.
[b] No information available.
[c] Questionable ownership.

Montana has one geographic area (Beaverhead [Sites Nos. 18 and 19]) that has favorable topographic and land use suitability, moderate soil suitability, moderate potential for ground water contamination, and a high potential for waterfowl contact. Site No. 16 at Sanders has suitable soils, low potential for ground water contamination, favorable topographic and land use suitability, and a high potential for waterfowl contact, but Site No. 17 in the same geographic area exhibits high potential for ground water contamination.

Nevada has two areas with potential for a demonstration site. The geothermal resource at Nye (Sites Nos. 15-19) has a projected industrial use, compatibility with topography and present and projected land use, and a small marsh near the site at present. The potential for ground water contamination is low and soil suitability is good, but the estimated potential for waterfowl contact is low. It is possible that waterfowl would frequent the area if water were available in sufficient quantities.

The White Pine 1 area (Sites Nos. 79 and 80) appears suitable for a demonstration site, according to parameters listed in Table 40, but is lacking information on soils, a determining factor in site selection. For this reason, White Pine 1 was not included in the final sites recommended as potential demonstration sites.

Washoe 5 (Sites Nos. 63-78) has a projected use for electrical generation, which indicates a sufficient volume of effluent, but insufficient area to hold the volume of effluent anticipated. Topographic and land use suitability at the site are apparently poor.

The only site in New Mexico, Socorro (Site No. 18), was eliminated from consideration as a demonstration site because of its poor topographic and land use suitability and high potential for ground water contamination.

Modoc 5 (Site No. 13) in northern California has a projected use for electrical generation but was eliminated because of a lack of soils information and high potential for ground water contamination.

Both areas in Oregon, Klamath 1 (Sites Nos. 14, 16, 17, and 19-21) and Klamath 2 (Sites Nos. 15 and 18), have poor topographic and land use suitability. They are both located in close proximity to Klamath Falls, a large populated area.

CONCLUSIONS AND FINAL RECOMMENDATIONS

Table 40 summarizes information that can be used to determine which of the areas and sites studied hold greatest potential for development of geothermal wetlands. It was determined that four factors (sufficient area, topographic suitability, land use suitability, and ground water contamination potential) are probably the most critical constraints with regard to wetlands development in the areas identified in Table 40.

A fifth factor, waterfowl contact potential, is also important, but can be viewed from two perspectives. The first is that wetlands development would be most successful in terms of waterfowl use (and productivity in the larger wetlands) in areas of high contact potential (i.e., along major flyways). A second view is that an equal or greater potential value is associated with development of waterfowl habitat in areas where it is currently a rare commodity.

Selecting the first perspective indicates that the Beaverhead area of Montana holds the greatest promise for development of geothermal waterfowl wetlands. Acceptance of the second viewpoint indicates that the Camas area of Idaho and the Nye area of Nevada hold equal if not greater potential. The only major constraint in these areas is low waterfowl contact potential. They are, however, areas of low habitat availability and this could be considered an added inducement to wetlands development.

It should be noted that many other potentially feasible areas may exist beyond those discussed in this report. For example, companies such as Sunoco Energy Development, Phillips Petroleum, and Union Oil are in various stages of development of geothermal resources. Efforts to obtain data for this report from companies involved in geothermal exploration and development, however, were not productive.

Careful attention should be paid to current investigations at the Raft River Geothermal Experiment Site, Idaho. Demonstration wetlands may indicate harvesting will not be a major detriment to wetlands ecology. Future studies should concentrate on gathering site-specific information needed for constructing a demonstration wetlands. This should include a careful chemical and physical analysis of the geothermal water at any one site and detailed geologic, soils, and hydrologic investigations. New information from current research (when available) on waterfowl or plant tolerance to heavy metals, fluorides, and other factors should be gathered to either increase or decrease concentrations found in Table 4 for Level 1 use.

APPENDIX A. STATE HYDROTHERMAL TABLES

Table A-1. Hydrothermal source chemical data for Idaho.

Area	Site No.	County	Location (Twn, Rg, Sec)	Water Source	Temp. (°C)	Flow (gpm)	TDS (ppm)	Sp. Cond. (μmhos/cm)	pH	Al ppm	As ppm	B ppm	Ba ppm	Ca ppm	Cl ppm	CO_3 ppm	Cr ppm	Cu ppm	F ppm	HCO_3 ppm	H_2S ppm	Hg ppm	I ppm	K ppm	Li ppm	Mg ppm	Na ppm	NH_4 ppm	NO_3 ppm	P ppm	PO_4 ppm	SiO_2 ppm	SO_4 ppm	Sr ppm
A[a]	1	Ada	3N, 2E, 11	W[b]	76	<1	295	420	8.5		0.007			6	3	19			17	120				1.4	0.05		89				0.01	80	21	
	2	Ada	3N, 2E	W	75				7.3					2	9					141				1.3			75					78	23	
	3	Ada	3N, 2E	W	80		290		9.0	tr*	<0.05	0.14	<0.20	2	10	4	tr*	0.08	14	70	tr*	<0.02		1.6	0.05	0.05	90					160	23	<0.01
	4	Madison	6N, 40E	W																														
B	5	Adams	16N, 2E	S[c]	65				7.6					39						71				17.0			420					110	660	
C	6[a]	Blaine	4N, 17E, 15	S	70.5				8.0					3	11					51				2.1			84					86	72	
	7[a]	Blaine	4N, 18E	S	81				7.3					2	5					51				1.9			69					96	35	
D	8	Boise	8N, 5E, 6	S	80	20			8.1					5	34					160				4.8			130					120	79	
E	9	Camas	1N, 13E, 29	S	66				8.0					1						51				3.0			54					73	12	
	10	Camas	1S, 13E, 34	S	70	25			7.3					4	15					226				2.5			99					77	13	
F	11	Cassia	15S, 26E, 23	S	96				7.7					130	900					36				35			1 110					97	61	
	12	Cassia	15S, 26E, 31	W	146	650								51	605				5	71				25		1.9	359					91		
	13	Cassia	15S, 26E, 23	W	143	800	2 000							38	661				8	42				35		0.1	389					170		
	14	Cassia	15S, 26E, 25	W	147	800								193	2 001				4	53			0.24	91	3.10		1 156	0.47		0.25		67	32	6.40
G	15	Elmore	4S, 10E	W	68	500			8.5					1	5					74				0.80			87					86	14	
	16	Gooding	4S, 13E, 31	S	65	1 200			7.5					1	66					141				1.6			91					97	15	
H	17	Franklin	13S, 42E	S	76				7.3					89	630					491				110			490					55	260	
I	18	Franklin	15S, 41E	S	77				7.0					160	5 400					699				660			3 100					80	50	
J	19	Valley	14N, 3E	S	70.5	20			7.7					2										1.9			100					78		
K	20	Adams	15N, 1W	S	70				7.8					17	140					24				3.8			200					72	200	
L	21	Custer	11N, 15E, 19	S	76	1 691	119	413	8.5			0		2	12	0			15	119				2.4		0	85		0.06		0.07	91	54	
M	22	Elmore	1N, 10E, 5	S	74																													
N	23[a]	Wash	11N, 6W, 21																															
	24	Wash																																

[a] Site or unspecified sites in the area are developed

[b] Well

[c] Spring

*tr - trace amount

Table A-2. Hydrothermal source chemical data for Montana.

Area	Site No.	County	Location (Twn. Rg. Sec)	Water Source	Temp (°C)	Flow (gpm)	TDS (ppm)	Sp Cond (μmhos/cm)	pH	Al ppm	As ppm	B ppm	Br ppm	Ca ppm	Cl ppm	CO_3 ppm	F ppm	Fe ppm	HCO_3 ppm	H_2S ppm	I^- ppm	K ppm	Li ppm	Mg ppm	Na ppm	NO_3 ppm	Pb ppm	PO_4 ppm	SiO_2 ppm	SO_4 ppm	Sr ppm	U ppm	Zn ppm
A	1	Lewis & Clark	12N 6W 32	W[a]	97		680	950	7.9			0.1		8	51		20.0	0.02	260			10.0	2.00	0.5	210	1.00			69	180	0.07		
	2[b]	Jefferson	8N 3W 16	S[c]	57	10	660	929	7.2			0.24		18	10	1	8.4	0.02	480	0.5		9.5	0.32	3.5	220		0.1	0.02	66	89			0.06
	3	Jefferson	5N 4W 10	S	76	582	420	523	8.5			0.36		2	19	4	11.0	0.02	161			3.8	0.24	0.1	120		0.1		100	74			0.01
	4[b]	Lewis & Clark	10N 4W 26	S	62	13	600	796	8.5			0.80		11	33	5	9.4	0.70	210	0.5		5.8	0.48	0.9	160		0.1		98	170			0.02
B	5[b]	Madison	5S 1W 28	S	83	21	1 030		7.7		0.02	0.61		6	120		11.0	0.02	442			17.0	0.26	0.6	340			0.06	96	220	0.18		
	6	Madison	10S 1E 9	S	68	53	363	659	8.6	0.039	0.007	0.04	0.1	0.2	23	9	18.0		157		0.01	1.9	0.06	0.8	120	0.28	0.003		55	53	0.07	0.0006	
	7[b]	Madison	4S 7W 28	S	53	26	1 860	2 160	6.8			0.92		290	46	1	3.3	0.10	230	1.1		24.0	0.18	73.0	160		0.1		46	1 130			0.08
	8[b]	Madison	3S 2W 6	S	50	53	333	471	8.6			0.02		10	6	2	6.2	0.02	63	0.5		1.6	0.05	0.1	91		0.1		46	140			0.01
	9[b]	Madison	3S 1W 14	S	56.5	98	646	903	7.6			0.10		17	23	1	7.4	0.02	380	1.0		10.0	0.09	3.2	180		0.1		88	130			0.04
	10[b]	Madison	2S 6W 1	S	72	60	610	808	8.2			0.25		9	31	2	8.7	0.02	170	1.0		6.4	0.34	0.3	170		0.1		110	190			0.01
C	11	Park	8S 8E 32	S	65	132	2 080	2 460	6.5			0.46		320	45	1	3.6	0.16	297	1.0		23.0	0.24	58.0	230				49	1 200			0.01
	12[b]	Meagher	9N 7E 18	W	46	397	1 530	2 220	6.5			9.10		44	180	0.1	7.4	0.11	830	0.7		20.0	1.30	12.0	480		0.1		51	310			0.02
	13[b]	Gallatin	2S 4E 14	S	50-55	60	430	624	8.6			0.20		9	46	3	9.2	0.02	132	0.6		2.8	0.04	2.7	120		0.1		66	110			0.01
D	14[b]	Deer Lodge	5N 10W 24	S	77	159	1 250	1 510	6.5			0.10		220		1		0.05	258	0.7		26.0	0.36	22.0	120		0.1		56	670			0.11
	15[b]	Deer Lodge	3N 10W 2	S	70	264	560	701	8.4			0.30		4				0.02		1.6		3.9	0.64	0.1	170		0.1		85				0.10
E	16[b]	Sanders	21N 24W 3	S	45	53	330	376	9.4			0.34		1	8		5.6		189	7.4		1.7	0.04	0.1	85				70	38			0.01
	17[b]	Sanders	18N 25W 9	S	43	18	190	205	8.9					4	3	0	2.1		71			1.5	0.01	0.2	39				77	29			
F	18[b]	Beaverhead	4S 12W 29	S	49	29	180	209	8.9			0.04		2	2	4	2.6	0.02	77	0.9		0.7	0.05	0.1	48		0.1		55	27			0.01
	19[b]	Beaverhead	5S 15W 25	S	58	264	670	972	6.8			0.83		10.0	8	1	2.0	0.02	610	0.6		10.0	0.32	3.7	240		0.1		52	45			0.12

[a] Well
[b] Site is developed
[c] Spring

Table A-3. Hydrothermal source chemical data for Nevada.

Area	Site No	County	Location (Twn Rg Sec)	Water Source	Temp (°C)	Flow (gpm)	TDS (ppm)	Sp Cond (umhos/cm)	pH	Ag ppm	Al ppm	As ppm	B ppm	Ba ppm	Be ppm	Bi ppm	Br ppm	Ca ppm	Cd ppm	Cl ppm	CO_3 ppm	Cr ppm	Cs ppm	Cu ppm	F ppm	Fe ppm	HCO_3 ppm	H_2S ppm	Hg ppm	I ppm	K ppm	Li ppm	Mg ppm	Mn ppm	Mo ppm	Na ppm	Nb ppm	NH_4 ppm	Ni ppm	NO_3 ppm	Pb ppm	PO_4 ppm	Ra μμc/l	Rb ppm	Sb ppm	Sc ppm	Se ppm	SiO_2 ppm	Sn ppm	SO_4 ppm	Sr ppm	S_2O_3 ppm	Te ppm	U ppm	W ppm	Zn ppm
A	1	Churchill	19N 31E	W[a]	96			6,910					15					108		2,200	<1				5		90				42	1.9	1.7			1,480												170		190						
	2	Churchill	19N 31E	W	100			7,420	7.5									91		2,080	0						104						1.0			1,400														190						
B	3	Elko	33N 52E 33	S[b]	79			625	7.6									60		12							335				16		15.0			45												70		52						
C	4	Elko	34N 55E	S	87																																																			
	5	Elko	34N 55E	S	88																																																			
D[c]	6	Eureka	31N 48E 8	S	98	26		1,020	9.0				2.1					1		69	32				17		321				16	1.3	<0.1			230												320		130						
	7	Eureka	31N 48E 17	S	88							0.5		0.05		0.01	0.14	1		56			0.20			<0.07					8			<0.003	0.02	210								0.15	0.01	<00002		330						<0.0002	0.15	
	8	Eureka	31N 48E 17	S	78							0.01		0.19			0.12	3		42			0.12			0.07					31			0.12	0.003	250								0.2	0.005	0.0007		300						0.0005	0.01	
	9	Eureka	31N 48E 17	S	84		964	1,006	9.7	<0.02		0.002		0.04	<0.005	0.01		9	0.010	67	152	<0.02	1.04	<0.01	19	0.9	0		<0.0005		14	2.6	0.8	0.01		229		0.5	0.05	<0.1	0.06	<0.1		0.27	0.10		0.001	345	0.05	128	0.02					2.3
	10	Eureka	31N 48E 17	S	96		1,100		9.5				2.2					<1		44	161						148				29		<1.0			241												444		78						
	11	Eureka	31N 48E 17	S	77						0	0	7					2		47	173				11	tr*	129	0			33		0			239		4.0										449		97		1.0				
	12	Eureka	31N 48E 17	S	96				9.5		0		2				0.4	0.8		30	149				15	0.04	116	5.5		0	16	1.3	0	0		230		0.5		0.4								373		89	0					
	13	Eureka	31N 48E 17	W	100		1,2[illegible]	1,211	9.9	<0.004		0.02		0.10	<0.005	<0.1		10	<0.002	62	288	<0.04	1.02	<0.004	16	0.05	0		<0.0002		31	3.2	0	<0.01		263	10.0	0.9	0.03	<0.1	<0.02	<0.1		0.63	0.20		<0.001	458	<0.20	127	0.04		5.0			0.01
	14	Eureka	31N 48E 17	W	100		1,200	1,130	9.7		0.66	0	2.4				0	0.8		49	224				15	0	39			0	30	1.6	0.2			332		0.4		0		0.06						534		90	0.21					
	15	Nye	11N 43E 7	S	88	450	367	472	8.7		0.1		0.3					1.2		12	24				15	0.05	112				2		0	0		104				0		0.1	0.2					105		40				0.10		
	16	Nye	11N 43E 7	S	92	150	382										31	13		15						tr*	102						3			80										0		88		60						
E	17	Nye	11N 43E 8	S	95	92		479	8.3				0.2					1.3		12	3				14		146				3	0.3	0.1			110												98		53						
	18	Nye	11N 43E 8	W	94	79		499	8.3				0.2					1.4		12	3				15		165				3		0.1			110	10.0											105		55			5.0			
	19	Nye	11N 43E 8	W	100	25	390	488	9.3	<0.004		00001		00001	<0.005	<0.1		9	<0.002	15	44	<0.04	0.32	<0.004	16	0.06	76		0.0004		3	0.7	0.02	0.01		111		<0.1	0.02	<0.1	0.02	0.9		0.06	0.20		<0.001	105	<0.02	49	0.04					0.03
F	20	Humbolt	36N 40E 29	S	74	198		810	6.5				1.1					33		18	<1				2		429				22	0.4	6.8			130												66		56						
G	21	Lyon	15N 25E 16	W	97	400	1,130	1,580	8.3				1					39		46	2				8	0.02	66				12		0			291				0								99		596						
	22	Lyon	15N 25E 16	W	97			1,550	8.5									38		46							70				15		0.2			277												115		580						
	23	Lyon	15N 25E 16	S	94			1,610	8.1				10					39		55					8		74				14		0.1			300												110		620						
	24	Lyon	15N 25E 16	W	105	25	1,090	1,490	8.0				1					37		45					8	0.01	80				12		8.7			276				0								100		556						
	25	Lyon	15N 25E 16	W	108		1,279											37		52	6				9	0.02	73																							760						
	26	Lyon	15N 25E 15	W	100		1,250	1,656	8.6	<0.02		0.001		0.14	0.007	<0.1		46	<0.010	54	12	<0.02	0.001	<0.01	9	0.41	49		<0.0005		14	0.3	0.1	0.04		332		0.5	0.08	<0.1	0.07	0.2		0.15	0.10		<0.001	100	0.05	658	0.25					1.03
	27	Lyon	15N 25E 15	W	97	400	1,210	1,630	8.6				1					40		49	12				8	0.06	52				13		1.0			313				0								109		642						
H	28	Pershing	28N 32E 33	W	66		5,040	10,200	7.9				5.4					115		2,580	0				4	0.40	186				120		19.0			1,700				42.0								76		282						
I	29	Washoe	32N 23E 10	S	97				7.7									73		2,150	0						84				121		2.2			1,440												184		386						
	30	Washoe	32N 23E 10	S	64				7.7				10					80		2,430	0				5		83				130		2.3			1,800												186								
	31	Washoe	32N 23E 10	S	75				7.6									73		2,100	0						90				110		2.0			1,560												178								
	32	Washoe	32N 23E 10	S	98				7.4									95		2,100	0										140		1.0			1,610												174								
	33	Washoe	32N 23E 10	S	93			7,800	7.6									73		2,880	0						66				135		2.0			1,590												172		360						
	34	Washoe	32N 23E 10	S	63				7.8									75		2,180	0						82				148		2.2			1,590												176								
	35	Washoe	32N 23E 10	S	96			7,620	7.1									68		2,180	0						156				134		2.4			1,560												172		410						
	36	Washoe	32N 23E 15	S	63				7.6									74		1,915	0						74				130		1.0			1,380												182		356						
	37	Washoe	32N 23E 15	S	86			7,610	7.2				9.9					68		2,200	<1				4		83				130	1.6	1.2			1,400												165		400						
	38	Washoe	32N 23E 15	S	84		4,596	7,830	8.1	<0.02		0.003		<0.04	<0.005	<0.1		89	0.01	2,238	0	<0.02	4.76	<0.01	5	0.09	91		00007		113	3.5	1.0	00002		1,548		0.6	0.05	0.7	0.06	0.2		1.73	0.30		<0.001	170	0.05	385	0.40					0.14
	39	Washoe	32N 23E 15	S	65				7.8									70		2,340	0										133		2.2			1,420												192								
	40	Washoe	32N 23E 15	S	84			7,600	7.7				10					96		2,350	0				5		82				136		2.3			1,360												172		400						
	41	Washoe	32N 23E 15	S	78				7.0									73		2,130	0										140		2.3			1,600												180		360						
	42	Washoe	32N 23E 18	S	65				8.2									75		2,100	0										135		2.8			1,530												172								
	43	Washoe	32N 23E 18	S	74				7.2									174		2,075	0										134		2.5			1,540												172								
	44	Washoe	32N 23E 16	S	85				7.0									73		2,130	0										143		2.4			1,470												165		290						
	45	Washoe	32N 23E 16	S	67			6,800	7.9									66		2,100	400						0				126		8.1			1,510																				
	46	Washoe	32N 23E 16	S	67													66		100	400												6.1			510																				
	47	Washoe	32N 23E 15	S	100		4,486				tr*							5		2,146	0					tr*	97									1,576												199		363						
J	48	Washoe	26N 20E 12	W	82		4,615	7,100	7.4									163		1,950	0						50	0			120		0.1			1,040												117		335						
	49	Washoe	26N 21E 6	W	67	50	3,676	6,072	8.1	<0.01		<0.001		0005	<0.005	<0.1		282	0.006	1,841	0	<0.02	4.17	<0.01	3	0.02	11		<0.0001		31	0.8	0.1	<00001		1,080		<0.1	0.02	<0.1	<0.02	<0.1		0.80	<0.10		<0.001	95	<0.02	338	4.20			0.008		0.02
	50	Washoe	26N 21E 6	W	66		4,225	6,500	8.4				5.1					260		1,880	0				3		22	0			160		0.1			1,100												110		340						
	51	Washoe	26N 21E 6	S	66		4,680	7,200	7.6									315		1,850	0						100	2			280		0.4			1,150												82		330						
K[c]	52	Washoe	19N 19E 25	W	64		780	1,035	8.1		2.0		1.4					16		33	0				4		131				5.5	0.14	0.4			189					0.11							93		305						
	53	Washoe	19N 19E 25	S	38-93		661											21		34						2.00	126						2.0			167												97		264						
	54	Washoe	19N 19E 26	W	78		1,057	1,320	8.2				1.2					25		53					6		101				8		0.3			293					0.2							103		465						
	55	Washoe	19N 19E 26	W	85		1,012	1,430	7.8				2.1					22		53					5		99				7	0.8	0.8			259					0.11							92		478						
	56	Washoe	19N 19E 26	W	85		984	1,423	8.4				2					14		54					5		97				8	0.2	0.2			243												111		448						
	57	Washoe	19N 19E 26	W	85		1,033	1,454	8.3				2.1					13		54					5		108				8	0.2	0.2			226					0.06							114		463						
	58	Washoe	19N 19E 26	W	90		975	1,367	8.3				2.0					23		50					5		86				7	0.2	0.2			243					0.19							102		457						
	59	Washoe	19N 19E 26	W	90		918	1,185	7.7				1.8					29		42					5		146				7	0.2	0.8			203					0.04							135		348						
	60	Washoe	19N 19E 26	W	82		980	1,327	7.9									33		52						tr*	tr*				9		0.9			241												95		478						
	61	Washoe	19N 19E 26	W	80		959	1,070	7.5		tr*		1.7					20		53					5		95				7	0.2	0.3			248					0.09							104		419						
	62	Washoe	19N 19E 26	W	85		969	1,345	8.0				1.9					23		48					5		86				8	0.2	0.1			236					0.11							106		455						
L	63	Washoe	18N 20E 33	W	75		182	348	9.0				0.1					2		8	19						146				7		0.4			69												5		2						
	64	Washoe	18N 20E 33	W	92		2,066		8.6				24					4		747	104				2		191				56	6.0	0.5			605												222		105						
	65	Washoe	18N 20E 28	W	75		1,862		7.1									27		805					2		256						11.0			630														130						
	66	Washoe	18N 20E 33	S	89		2,354		7.9			2.7	49					5		865	2				2		305				71	7.6	0.8			653												293		100						
	67	Washoe	18N 20E 33	S	94	13		3,340	7.2				47					16		837	20				2		364				66	7.5	0.7			680												270		73						
	68	Washoe	18N 20E 33	S	95		2,542		8.2			1.3	30					12		949	0				2		292	5			75	7.0	0.5			707												317		129						
	69	Washoe	18N 30E 33	S	75-95	825		3,210	7.9		0.5	2.7	49				0.20	5		865					2	0.5	305			0.1	71	7.6	0.8	00005		653									0.40			293		100	0.05					
	70	Washoe	18N 20E 33	W	90													53		490						3.50	337						3.0			390														26						
	71	Washoe	18N 20E 34	W	66		316		7.8									66		5							158						8.8			5.8														72						
	72	Washoe	18N 20E 34	W	70		423		7.2									67		8							242						18.0			18														72						
	73	Washoe	18N 20E	W	92		2,322		7.4				52					15		885	0						340				63		1.0			667												245		122						
	74	Washoe	18N 20E	W	95		2,505		8.7				58					11		986	100						143				66		1.4			728												245		128						
	75	Washoe	18N 20E 28	W	145		2,226	3,150	7.6				46					11		836					2	0.01	337				64	7.6	1.0			640												299		94						
	76	Washoe	18N 20E 28	W	132		2,230	3,360	8.7		0		17					1		863	65				2	0.01	172				68	10.0	0	0		660				2.0								121		130				0007		
	77	Washoe	18N 20E 33	W	140													36		308						2.20	339						5.0			313														82						
	78	Washoe	18N 20E 32	W	161			85	6.5				1					6		0.5					0			2					0			9				tr								14		24						
M	79	White Pine	21N 63E 24	S	79			522	6.4				0.04					63		5				0.01	1	0.02	303				6	0.1	21.0			16								0.03				52		26						
	80	White Pine	21N 63E 24	S	79	625	349											67		7	tr*					0.19	324						21.0			26				0.1								54		25						
N	81[c]	Lincoln	4S 67E 4		67			400	7.2									34		8					1		200				14		4.8			39												106		30						
O	82	Esmeralda	1S 36E	W	158																																																			
P	83	White Pine	24N 65E	W	152																																																			

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[a] Well
[b] Spring
[c] Site or area developed
*tr - trace amount

Table A-4. Hydrothermal source chemical data for New Mexico.

Area	Site No.	County	Location (Twn, Rg, Sec)	Water Source	Temp. (°C)	Flow (gpm)	TDS (ppm)	Sp. Cond. (μmhos/cm)	pH	Al ppm	As ppm	B ppm	Br ppm	Ca ppm	Cl ppm	CO_3 ppm	F ppm	Fe ppm	HCO_3 ppm	I ppm	K ppm	Li ppm	Mg ppm	Mn ppm	Na ppm	NO_2 ppm	NO_3 ppm	PO_4 ppm	Se ppm	SiO_2 ppm	SO_4 ppm
A	1	Hidalgo	25S, 19W, 7	W[a]	99		1 057	1 560	9.1			0.45		18	89	23	12	0.05	32		16	0.66	0.1	0.16	302	0.01	0.20	0.02		103	490
	2	Hidalgo	25S, 19W, 7	W	96		1.110	1 510	7.6					22	80	0	13		153				1.5				0.20			135	459
	3	Hidalgo	25S, 19W, 7	W	102									20				0.63			24	0.80	0.1		347						
	4	Hidalgo	25S, 19W, 7	W	75		620	835						28	42				228		8		11.0		150						169
	5	Hidalgo	26S, 20W	W	99									22	82				159		21				324					154	475
B	6[b]	Dona Ana	23S, 2E, 34	W	25-45		1 000	1 460	8.1	0.04	0.01	0.35	1.11	17	580	0	3	1.50	242	0.03	32	0.25	12.3	1.50	275	0.003		0.01	0	49	
	7[b]	Grant	13S, 13W, 10	S[c]	52	10	335	390	8.4	0.08	0.004	1.72	0.67	10	67	1	3	0	101	0.01	2	0.13	0.1	0.04	105	0.005		0	0	58	
C	8[b]	Grant	13S, 13W, 5	S	64			620	7.5	0.03			0.85	20	106	21	9	0.05	104	0.14	3	0.32	0.1	0.10	148					53	97
	9	Catron	12S, 13W, 31	S	65	47	508	460	7.2			0.12		16	108	0	10	0	128		4	0.20	0.1	0	177					80	84
D	10[b]	Catron	5S, 19W, 35	S	37	6	223	242	9.2	0.23	0.007	0.037	0.76	3	12	19	2	0.08	97	0	0.15	0.10	0.1	0	69	0.2		0.05	0.005	40	
	11[b]	Taos	24N, 8E, 24	S	37-45	350		3 900	6.6	0.03		1.00	0.66	29	237	0	13	0.06	2 073		31	4.30	8.5	0.15	980	0	0.12			55	149
	12[b]	Sandoval	20N, 3E, 29	S	49	323	150	122	7.7		0.003	0.04	0.06	5	2	0	1	0.16	61		2		0.3	0	23			0.21		76	9
	13[b]	Sandoval	18N, 2E, 23	S	76	1	1 960	3 460	7.1		0.78	7.40	3.00	160	700	0	4	0.45	773		63	7.80	6.6	0.30	510	0	0	0.30		71	43
E	14	Sandoval	19N, 3E, 4	S	70		4 240	17 300	2.0			0.10		72	20	0	1	76.00			34	0.02	18.0	1.30	25		0.40			185	4.520
	15	Sandoval	20N, 3E, 35	W	135-285		2 970	2 225	8.0					0.28	121		24	12.60	623		27		0	0.50	83		0				335
	16[b]	Sandoval	18N, 2E	S	66				7.2					138	795				735		70				572					93	49
	17	Sandoval	19N, 2E, 13	W	197		2 500	2 920	7.4					78	400		3		1 300				42.0		550					115	200
F	18[b]	Socorro	3S, 1W, 22	S	33	292	220	330	8.4		0.05			22	13	0.4	0.22	0.25	157		3		3.1	0.05	52		0.96		0.014		29

[a] Well
[b] Site is developed
[c] Spring

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Table A-5. Hydrothermal source chemical data for northern California.

Area	Site No	County	Location (Twn. Rg. Sec)	Water Source	Temp (°C)	Flow (gpm)	TDS (ppm)	Sp Cond (μmhos/cm)	pH	Al ppm	B ppm	Ca ppm	Cl ppm	CO_3 ppm	Cs ppm	Cu ppm	F ppm	Fe ppm	HCO_3 ppm	H_2S ppm	Hg ppm	K ppm	Li ppm	Mg ppm	Mn ppm	Na ppm	Rb ppm	SiO_2 ppm	SO_4 ppm	Zn ppm
A	1	Lake	13N 7W	S[a]	99				8.1		628	26	900				1.4		2 600			44	6.4	23		1 340		203	680	
	2	Lake	13N 7W	W[b]	186																									
B	3	Lassen	28N 15E 8	S	95	132	879	2 860	8.4		4.0	14	160	2			4.4		44			5	0.08	<0.1		250	0.02	95	300	0.005
	4	Lassen	28N 16E 5	W	107																									
	5[c]	Lassen	29N 15E 23	S	96																									
C	6	Lassen	38N 7E 12	S	79	53	820	2 300	8.5		2.5	30	93	1			2.0		30			3	0.1	0.1	0.01	220	0.01	68	370	
	7	Modoc	42N 10E 29	S	110																									
	8	Modoc	42N 17E 6	W	98	79		2 700	8.4		5.7	16	200	2			5.1		57			5	0.1	0.1	0.01	280	0.03	100	320	0.014
	9	Lassen	38N 8E 15	S	78	4	880	2 600	8.6		3.2	30	110	2			2.6		31			6	0.12	0.1	0.01	240	0.02	85	370	
	10	Modoc	42N 10E	S	95	325						29										6.4				231		127		
	11	Modoc	42N 10E 29	S	95																									
	12	Modoc	42N 10E 29	S	91	331	899	2 800	8.1		3.8	20	160	1			2.1		45			6	0.15	0.1	0.01	250	0.02	110	300	
	13	Modoc	39N 5E 9	S	75	79	941	2 500	7.6		3.9	44	120				1.9		49			5	0.17	0.2	0.01	230	0.02	87	400	
	14	Modoc	44N 15E 23	W	160																									
	15	Modoc	43N 16E 12	S	85	132	1 110	3 3[illegible]0	7.7		7.6	28	220				5.4		63			9	0.15	0.1	0.01	300	0.04	110	370	0.005
	16	Modoc	45N 16E	S	86	<1.0						11							124			16				343		182	330	
	17	Modoc	39N 14E 29	W	77	3	1 220	3 000	7.8		4.5	19	150				4.0		63			11	0.4	0.1	0.012	330	0.06	130	510	
	18	Modoc	44N 16E 24	S	96	0	1 210	3 740	7.4		6.3	7.7	220	0			7.6		112			15	0.24	0.1	0.01	320	0.08	200	320	0.005
D	19[c]	Mono	5N 25E 34	S	69	13			6.7	0.004	9.9	64	200		0.4	0.02	4.5	0.05	1 880	0.5	0.0001	55	2.5	18	0.02	1 110	0.4	100	920	0.18
E	20	Napa	9N 6W	S	98	520			9.0		9.2	4.5	215				12.0		0.5			9	2.1	0		193		139	12	
	21	Napa	9N 7W 26	W	137																									
F	22	Plumas	22N 14E 13	S	73	26	1 370	3 870	8.2		7.4	37	460	0	0.2		2.2	0.06	41			7	0.42	0.1	0.022	410	0.06	60	340	
	23	Plumas	22N 14E 13	S	70	21	1 360	3 740	7.9		7.3	38	460	1	0.2		2.2	0.06	51			7	0.40	0.1	0.03	400	0.06	62	330	
	24	Sierra	21N 14E 32	W	94	13.2	1 570	4 720	7.9		8.8	39	540	1	0.2		2.6	0.06	50			13	0.65	0.1	0.01	450	0.11	98	370	

[a] Spring
[b] Well
[c] Site or unspecified sites in th area are developed

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Table A-6. Hydrothermal source chemical data for Oregon.

Area	Site No.	County	Location (Twn. Rg. Sec)	Water Source	Temp. (°C)	Flow (gpm)	TDS (ppm)	Sp. Cond. (µmhos/cm)	pH	Al ppm	As ppm	B ppm	Ba ppm	Br ppm	Ca ppm	Cl ppm	CO_3 ppm	Cs ppm	Cu ppm	F ppm	Fe ppm	HCO_3 ppm	H_2S ppm	Hg ppm	I ppm	K ppm	Li ppm	Mg ppm	Mn ppm	Na ppm	NH_4 ppm	NO_3 ppm	Pb ppm	PO_4 ppm	Rb ppm	Sb ppm	SiO_2 ppm	SO_4 ppm	Sr ppm
A[a]	1	Lake	39S. 20E. 27	S[b]	88	200		1,370	7.8	0.01	0.07	11.2	0.1	1.0	9	170	2	0.1	0.01	5.4	0.02	232		0.0017	0.10	9.0	0.15	0.10	0.02	280	1.80		0.06	0.18	0.04	0.2	130	240	0.17
	2	Lake	39S. 20E. 27	S	85	189	905	1,320	7.3			9.9			9	146				6.9	0.02	208				8.8		1.40		268		0.30					140	223	
	3	Lake	38S. 24E. 27	S	78	200		1,490	7.3	0.02	0.46	13.6	0.1	0.4	16	240	1	0.1	0.01	4.9	0.02	153		0.0004	0.10	11.0	0.40	0.20	0.03	280	0.60		0.06	0.58	0.07	0.2	180	200	0.12
	4	Lake	38S. 24E. 34	W[c]	99	3,785	1,130	1,580	8.7	0.65		18.0		0.9	10	263	36			5.2	0.15	70	0.3		0.10	12.0	0.39	0.50		298		1.00		1.4			169	209	0.31
	5	Lake	38S. 25E. 10	S	68	70		513	7.9	0.01	0.10	2.2		0.4	8	56	1	0.1	0.01	3.5	0.02	105		0.0001	0.03	7.9	0.04	1.00	0.02	92	0.18		0.06	0.18	0.02	0.2	77	59	0.05
	6	Lake	39S. 20E. 4	S	96	2,300		1,120	7.8	0.03	0.06	6.9	0.1	0.4	13	120	1	0.1	0.01	4.4	0.02	79		0.0004	0.08	8.5	0.15	0.10	0.02	210	0.31		0.06	0.25	0.04	0.2	140	260	0.32
	7	Lake	39S. 20E. 4	S	86	19	821	1,140	8.4			7.1			8	120	5			4.5	0.01	64				10.0		2.40		208		0.30					140	258	
	8	Lake	39S. 20E. 4	S	98	19		1,110	8.3			7.2			12	116	6					62				9.5	0.20			209		7.20					146	265	0.50
	9	Lake	39S. 20E. 27	S	69	186	531	813	7.7			7.0			15	99				3.1	0.06	84				2.2		0.40		152		0.20					66	152	
	10	Malheur	38S. 45E. 20	W	88			1,460	8.1			13.0				248										10.0	0.33			281									
B[a]	11	Malheur	18S. 45E. 20	S	73			1,530	7.5	0.02		9.4	0.1		19	360		0.1	0.01	6.1	0.02					16.0	0.28	0.80	0.04	310	1.00		0.06		0.09	0.2	130	100	
C	12	Harney	37S. 33E. 15	S	74	29	1,440	2,050	7.6			12.0			15	255				7.0		382				27.0	1.50			430		1.20					119	319	
	13	Harney	37S. 33E. 15	S	79		1,520	2,160	8.1			14.0			14	270				7.0		414				30.0	1.50	0.30		456		1.30					173	339	
D[a]	14	Klamath	38S. 9E. 28	W	73	151	881	1,230	8.7			0.9			25	56	8			1.6		32				4.4				221							87	431	
	15	Klamath	40S. 9E. 34	W	93	7,000		1,030	8.9			0.7			15	59	2			1.5		48				4.0	0.08	0.10		200							90	360	
	16	Klamath	38S. 9E. 33	W	71		812	1,100	8.5			0.7			22	50	4			1.4		43				3.8				207		0.20					83	393	
	17	Klamath	38S. 9E. 28	W	81		833	1,160	8.8			1.0			23	54	8			1.2	0.04	32				4.2				213							81	403	
	18	Klamath	40S. 9E. 27	W	90	1,703		920	9.5		0.01	0.8			15	56	9			1.5	0.26	37				4.1				190							90	270	
	19	Klamath	38S. 9E. 28	W	89		816	1,000	8.6	0.03	0.02				25	48	16			1.1	0.03	22				3.5		1.04	0.02	331	0.54	0.01					73	384	
	20	Klamath	38S. 9E. 20	W	88	946		1,050	8.2			1.0			24	58				1.4		44				3.9		0.01		195							31	400	
	21	Klamath	38S. 9E. 33	W	89	38		1,200	8.3			1.0			27	54				1.2	0.03	46				3.0		0.20	0.03	370							78	462	
E[a]	22	Union	3S. 38E.																																				

[a] Site or unspecified sites in the area are developed

[b] Spring

[c] Well

Table A-7. Hydrothermal source chemical data for Utah.

Area	Site No.	County	Location (Twn, Rg, Sec)	Water Source	Temp. (°C)	Flow (gpm)	TDS (ppm)	Sp. Cond. (μmhos/cm)	pH	B ppm	Ca ppm	Cl ppm	F ppm	Fe ppm	HCO_3 ppm	Li ppm	K ppm	Mg ppm	Na ppm	K ppm	NO_3 ppm	SiO_2 ppm
A	1	Beaver	26S, 9W, 34	W[a]	85	1	7,040	11,500			19	3,810	7		158		420	3.3	2,080	1.9	405	65
	2	Beaver	30S, 12W, 21	W	85	11	1,500	2,120	8.1		83	210	14	0.13	384		49	9.7	360	1.0	110	480
	3	Beaver	30S, 12W, 28	W	77	19	1,490	2,170	7.8		72	220	7	0.05	360		61	9.8	360	0.1	120	470
	4[b]	Millard	25S, 7W	W	77																	
	5[b]	Beaver	27S, 9W, 3	W	133																	
	6[b]	Beaver	27S, 9W, 3	W	205		7,067		6.3	25	8	4,090	5		180	20	448	0.01	2,437	0.1	560	59
	7[b]	Beaver	27S, 9W, 3	W	260		6,442		6.5	29	10	3,400	5		200	19	410	0.24	2,000	tr*	560	54
B.	8	Box Elder	9N, 3W, 27	W	74	40	3,350	5,300			56	1,100			1,620		110	62	1,000			14
	9[b]	Box Elder	10N, 2W	S[c]	105	5	85,000															
C	10	Sevier	25S, 4W	S	64	100	4,970	7,520	6.6		264	1,690	6		412		45	44	1,380	0	84	1,250
D	11[b]	Sevier	25S, 3W	S	76	40	2,700	4,100	7.6		282	630	3	0.07	354		63	34	562	0	54	898
	12[b]	Sevier	25S, 3W	S	77	40	2,600	4,100	7.8		200	665	3		159		66	34	597	0.3	51	928
E.	13	Sevier	22S, 1W	W	66																	
F.	14	Iron	36S, 15W, 18	W	149	1,000		4,000														
G.	15[b]	Salt Lake	4S, 1W	W																		
	16[b]	Salt Lake	3S, 1W	W																		

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[a] Well

[b] Site is developed

[c] Spring

*tr - trace amount

APPENDIX B. DISCUSSION OF INDIVIDUAL CONSTITUENT EFFECTS ON BIOTIC COMPONENTS OF WETLANDS ECOSYSTEMS

ALUMINUM

Aluminum (Al) has been measured in the geothermal liquids characterized in Task 1 in concentrations ranging from 0 to 2.0 ppm. Most soils contain relatively large amounts of total aluminum, from 1 to 8%. To be toxic to plants, aluminum must be present in soluble forms above concentrations of 20 ppm. Solubility of aluminum is greatly increased in acidic soils; a pH of 4.5 is needed to keep aluminum in solution (Stout and Johnson 1957).

Flora

Traces of aluminum may be essential to some plants, because aluminum is widely found in low concentrations in plant tissue. Irrigation water of 20 ppm is considered safe for short-term use on sandy soils. For continuous use, the safe level drops to 1.0 ppm (U.S. Environmental Protection Agency 1976).

Crop plants considered tolerant of soluble aluminum include oats and rye. Aluminum has been found to stimulate growth in these species at concentrations of 3.4-13.6 ppm. Sensitive plants include corn, barley, and sorghum; they are injured by 1 ppm aluminum in solution (McKee and Wolf 1963). Data were not found on the effects of aluminum on marsh species.

Small quantities of aluminum reduce the toxic effects of sodium in the substrate and reduce the symptoms of manganese poisoning (McKee and Wolf 1963). The addition of lime to soils reduces harmful effects of high aluminum concentrations.

Fauna

Aluminum toxicity to aquatic invertebrates is largely unknown. Anderson (1948) reported that the threshold concentration of Daphnia magna was approximately 6.7 ppm of aluminum chloride. Aluminum is not known to be bioaccumulated.

Freshwater fish studies have been limited to sticklebacks, eels, and trout. The range in lethal concentrations is from 0.07 to 5.0 ppm. Mosquitofish had a 96-hour LC_{50} of 133 ppm $AlCl_3$ (Wallen et al. 1957), and killifish experienced lethal effects from 36-hour exposure to 14 ppm $AlSO_4$ (Thomas 1915).

AMMONIA-AMMONIUM

Ammonia (NH_3) dissociates in water to form a pH dependent equilibrium reaction with its ionized form, ammonium (NH_4^+). The more toxic state is NH_3. The formation of this un-ionized state is favored as pH, temperature, and salinity increase and as oxygen content decreases (U.S. Environmental

Protection Agency 1976). The geothermal fluid data surveyed report in terms of concentrations of NH_4, although this is probably a total for NH_3 and NH_4^+. These concentrations range from <0.1 to 4.0 ppm.

Fauna

Ammonia toxicity to aquatic invertebrates is greater in soft water than hard water. The snail *Physa heterostropha* was reported to have a 90.0-ppm, 96-hour TLm in soft water and a 133.9-ppm, 96-hour TLm in hard water at 20° C. The same bioassay procedure conducted at 30° C did little to alter these values (McKee and Wolf 1963).

Freshwater fish have been shown to be more sensitive. Warmwater species, including bluegill sunfish and minnows, have shown toxicity responses to concentrations ranging from 3.1 to 24.7 ppm (McKee and Wolf 1963). Boyd (1979) reports that toxic levels for warmwater fish range between 0.6 and 3.8 ppm. Growth in channel catfish was reduced when NH_3 measured 0.12 ppm.

ANTIMONY

Antimony (Sb) is a silvery-white metal that may occur briefly in the dissolved state through its water-soluble salts such as antimony potassium tartrate, antimony trichloride, and antimony sulfate. Dissolved antimony quickly precipitates out into the sediments. Antimony concentrations in the geothermal fluids under study range from 0.005 to 0.4 ppm. Antimony compounds can be toxic and are noted to be accumulated in certain forms of marine life (McKee and Wolf 1963).

Fauna

Bioassay studies have been conducted on *Daphnia magna* using antimony ammonium tartrate and antimony trichloride (McKee and Wolf 1963); threshold effects were noted to occur at 9 ppm and 37 ppm, respectively. Fathead minnows have been studied in relation to antimony potassium tartrate, antimony trichloride, and antimony trioxide. The 96-hour LC_{50}s have been reported for both soft and hard water bioassays. Tests proved inconclusive regarding toxic effect of water hardness; however, antimony trichloride appeared the most toxic to the fathead minnow. The 96-hour LC_{50} was 9 ppm in soft water and 17 ppm in hard water. Potassium tartrate had LC_{50} values of 20 ppm in soft water and 12 ppm in hard water.

ARSENIC

Arsenic (As) is considered a minor constituent of study area geothermal waters; it is found in concentrations ranging from 0 to 2.7 ppm. Arsenic found in soils chemically resembles phosphate. It tends to be retained in the soil, but can be leached when in solution. Toxicity of arsenic depends on the oxidation state. The pentavalent state (most common form in aerated soils) is of relatively low toxicity, whereas the trivalent state is highly toxic (Dvorak and Lewis 1978).

Flora

Concentration of available arsenic in the soil in a form that can be absorbed and translocated by plants varies from 0 to 500 ppm.

It is recommended (Geonomics, Inc. 1978) that water used for irrigation contain no more than 10 ppm arsenic for short-term use or 1.0 ppm for continuous use. Many crop plants are affected by concentrations as low as 0.5 ppm arsenic. The U.S. Environmental Protection Agency (1976) recommended that effluent to be used for irrigation purposes contain no greater than 0.1 ppm arsenic.

Plants grown on normal soils usually contain less than 1 ppm arsenic. Low concentrations of arsenic can actually stimulate growth. In species that have evolved tolerance, roots store arsenic as an insoluble residue. Arsenic that is translocated is concentrated in older leaves. In non-tolerant species, toxicity first appears in root systems and limits growth before much is translocated to other plant parts. When translocation does occur, arsenic acts to degrade chlorophyll, thus reducing photosynthesis and eventually productivity (Salisbury and Ross 1969).

The trioxide anion of arsenic has no effect on the growth of alkali bulrush at 5 ppm. The tolerance limit of arrowhead to sodium arsenite appears to be 4.0 ppm (U.S. Environmental Protection Agency 1976). Water milfoil, waterweed, and a blue-green alga tolerate between 6 and 10 ppm sodium arsenate before toxicity becomes apparent. Pondweeds will tolerate up to 5.0 ppm of the trioxide form before growth is hindered (Becker and Thatcher 1973). Sugar beets can tolerate 23 ppm when grown in sandy soils. Cereals and grasses are relatively tolerant to arsenic, whereas legumes and corn are not (McKee and Wolf 1963).

There is no evidence for bioaccumulation problems with respect to arsenic in the food chain. Lower trophic levels may accumulate arsenic, but not in sufficient quantities to be toxic to animals.

The addition of organic matter, zinc, iron, or aluminum compounds to the soil may have an antagonistic effect on arsenic present, keeping toxicity levels low. Phosphate addition may have a synergistic effect (Broadbent 1957).

Fauna

Arsenic has been shown to accumulate in aquatic organisms. Marine species concentrate from 10 to 100 times more arsenic than their freshwater counterparts (Dvorak and Lewis 1978). Transference of arsenic in the food chain is reported to have relatively low toxicity because the organically bound species of this element are less harmful than the ionic species (U.S. Environmental Protection Agency 1976).

The acute toxicity of arsenic to aquatic invertebrates ranges from 1.1 to 7.3 ppm (Becker and Thatcher 1973; Dvorak and Lewis 1978). The chronic toxicity of the arsenic ion to *Daphnia magna* was measured at 2.85 ppm (3 week-TLm).

Sixteen percent reproductive impairment of Daphnia broods resulted from exposure to 0.52 ppm arsenic ion. No toxic effects were noted for crabs exposed to 3.1 ppm for 90 days, for mayfly nymphs exposed to 3-14 ppm, and for dragonflies and damselflies exposed to 10-20 ppm (McKee and Wolf 1963).

Freshwater fish have been reported to withstand greater levels of arsenic than invertebrates. Toxicity levels affecting minnows range from 11.6 to 60 ppm. Arsenic was toxic to bluegills and crappies at 15 ppm (McKee and Wolf 1963). Largemouth bass, redear sunfish, and white crappie were not killed at arsenic concentrations of less than 5 ppm (Dvorak and Lewis 1978).

BARIUM

Barium (Ba) is a minor constituent of geothermal effluent, ranging between 0.00001 and 2 ppm. Barium is found in only small quantities in soils. Most naturally occurring barium is found in the form of barytes. Barium ions react with sulfates or carbonates to form insoluble barium salts which are unavailable to plants (McKee and Wolf 1963). Soils may become infertile if the exchangeable barium exceeds the exchangeable calcium (Dvorak and Lewis 1978). Barium concentrations may become as high as 35,000 ppm in soils around barite mines (Viets and Hanway 1957).

Flora

Irrigation waters usually do not contain soluble barium compounds; as a result, no tolerance limits have been set for this constituent. Soluble salts are toxic in moderate levels.

Plants normally do not utilize barium. Only trace amounts have been found in leaf tissue, although analysis for this element is not routinely performed (Salisbury and Ross 1969). Most plants do not exhibit toxic effects unless conditions are extreme. Waterweed, a submergent marsh species, is killed by concentrations as low as 10 ppm soluble barium (Becker and Thatcher 1973). A green alga, Chlorella vulgaris, is tolerant to soluble barium under anaerobic conditions (Antonovics et al. 1971).

This element is not thought to be a bioaccumulator, since most plants do not take up appreciable quantities.

Some authors report that concentrations of barium need to be extreme before toxicity occurs. Others indicate that any quantities, no matter how small, are toxic to plant life.

Fauna

McKee and Wolf (1963) report that barium chloride has been shown to be toxic to Daphnia at concentrations ranging from 170 ppm to greater than 200 ppm in 48-hour TLm studies. Immobilization of Daphnia occurred at 29 ppm in a study conducted at 25° C. The cladoceran Leptodora kindtii was immobilized at 12 ppm in waters between 20 and 25° C, while the copepod Cyclops vernalis withstood up to 123 ppm before being immobilized. The lethal levels of $BaCl_2$ for two species of freshwater snail (Bulinus contortus and Planorbis glabratus) were 14.3 and 11.1 ppm, respectively. Barium nitrate was shown to be of comparable toxicity to barium chloride in the previously mentioned study of Bulinus and Planorbis. The lethal level for both snail species was 20 ppm.

Mosquitofish and minnows show a much higher tolerance to this chemical than do invertebrates. Barium chloride appears less toxic than barium nitrate, as the range in lethal levels for mosquitofish was from 1,640 to 4,400 ppm $BaCl_2$, compared with 400 to 760 ppm of $Ba(NO_3)_2$ for sticklebacks. Goldfish responded to both barium species similarly, with lethal limits of 200 ppm $BaCl_2$ and $Ba(NO_3)_2$ (McKee and Wolf 1963).

Although Ba toxicity has been shown in studies conducted using barium salts, U.S. Environmental Protection Agency (1976) has not set criteria for this chemical because it is rarely found in a dissolved state in natural waters. Because of the scarcity of this element in the geothermal waters under study, Ba is not considered a limiting factor.

BERYLLIUM

Beryllium (Be) is usually unavailable in soils because of its ease in displacing other divalent ions in the cation exchange complex. This property fixes beryllium strongly in soils. It is chemically similar to aluminum and can substitute for it in soil complexes. Concentrations of beryllium in uncontaminated soils range from 0.1 to 40 ppm, with most around 6 ppm. Solubility of beryllium is greatest in acidic soils and, therefore, is more readily available to plants at low pH (Dvork and Lewis 1978). Beryllium concentrations in the study area geothermal liquids range from 0.005 to 0.007 ppm.

Flora

In soluble form (low pH), beryllium can inhibit plant growth. Concentrations in irrigation water range between 0.1 and 1.0 ppm. At a pH of 11.2, beryllium has been found to be beneficial to plants with a magnesium deficiency (U.S. Environmental Protection Agency 1976).

Soluble beryllium tends to accumulate in plant roots, affecting enzyme systems. When translocated to tops, leaves accumulate higher levels than shoots, inhibiting photosynthesis (Salisbury and Ross 1969). Reduced growth is exhibited at concentrations ranging between 0.5 and 2 ppm in legumes. Germination is retarded at 15 to 120 ppm beryllium in the mustard family. Soluble beryllium has been shown to decrease yields in crop plants where insoluble compounds had no effect on plant growth (McKee and Wolf 1963).

No reported instances of beryllium bioaccumulation were found. Soil pH affects solubility (and, therefore, toxicity) to plants; pH's above 5.5 reduce toxicity. It is not known how other factors (e.g., metals) interact with beryllium.

Fauna

In elemental form, beryllium is almost nonexistent in water, but it is found in the soluble compounds of beryllium chloride, nitrate and sulfate. Toxicity of these compounds to aquatic fauna is dependent on the hardness of the water, with soft water (low pH) 100 times more toxic than hard water.

No data were found regarding beryllium toxicity to aquatic invertebrates; however, studies on salamander larvae report a tolerance to 10 ppm in hard water, with a reduction in survival time in soft water when exposed to the same concentration.

Freshwater fish species used in beryllium toxicity studies include the common guppy, fathead minnow, and bluegill sunfish. Toxic concentrations for these species range from 0.15 to 1.3 ppm in soft water and from 11.0 to 20.3 ppm in hard water (McKee and Wolf 1963).

BORON

Boron (B) is a secondary constituent in geothermal waters, with concentrations ranging between 0 and 828 ppm. It usually exists in soils as an undissociated acid at pH's less than 8.5 and is relatively leachable. The addition of lime increases the sorption of boron by soils, rendering it unavailable for uptake by plants. Excess boron is frequently found in alkaline soils (Russel 1957).

Flora

Irrigation water at a concentration of 0.75 ppm should protect sensitive plant species from boron toxicity. For short-term use boron concentrations of 2.0 ppm are considered safe (Geonomics, Inc. 1978).

Boron is an essential micronutrient for vascular plant species. Concentrations required range between 15 and 20 ppm, but there is a narrow margin between deficiency and toxicity (Salisbury and Ross 1969). Concentrations of 50 ppm boron have been found in leaves, where accumulation tends to occur. Values up to 250 ppm have been detected without apparent toxicity. Generally, monocots require less boron than dicots. Several crop species have been identified as boron-sensitive, -semitolerant, and -tolerant species (McKee and Wolf 1963). Availability of boron is directly proportional to the amount of moisture in the soil. Low moisture availability restricts the mass flow of ions to root surfaces, thereby limiting uptake.

At the Raft River Irrigation Experiment, crop species were grown using geothermal effluent as irrigation water. Most species grown are typical of those farmed as food sources for waterfowl on State and Federal refuges. Preliminary results indicate no appreciable differences in tissue concentrations of boron between plants irrigated with geothermal effluent and those irrigated with "fresh" water (Table B-1). The range of boron concentration in Raft River geothermal effluent is 0.16 to <1.0 ppm. Some crop species have the ability to accumulate and concentrate boron from low concentrations in irrigation water (Stanley 1979).

Table B-1. Boron concentrations found in forage species, Raft River irrigation experiment.

Crop species	Boron concentration (ppm)	
	Geo[a]	Fresh[b]
Brome	26	15
Alfalfa	65	54
Barley	7	25
Orchard grass	26	22
Fescue	29	18
Wheat	22	17

[a] Geothermal effluent irrigation.

[b] Freshwater irrigation.

Wetlands species (bulrush, sedge, cattail, and reed) have the capacity to absorb boron from soils at concentrations of 14.6, 21.4, 24.5 and 8.2 ppm dry weight, respectively. No toxic effects were observed at any of the above concentrations (Lee et al. 1976). Duckweed tends to accumulate large amounts of boron relative to other aquatic plants. Quantities absorbed are in excess of one order of magnitude greater than the standard range (McNabb 1976).

There is no evidence for accumulation of boron through the food chain.

Fauna

Boron tolerance levels of aquatic fauna have been shown to be variable. In bioassays, *Daphnia magna* appears to be the most sensitive organism tested. *Daphnia* immobilization thresholds occurred in studies using sodium borate at concentrations ranging from 120 to <240 ppm. Sodium perborate almost immobilized *Daphnia* at <5.2 ppm (Becker and Thatcher 1973).

Toxicity studies on several fish species have utilized boric acid and sodium borate in their bioassays. Overall, the toxicity levels range from 1,600 to 19,000 ppm (McKee and Wolf 1963). This element generally does not appear to be toxic to fish, although invertebrates have shown toxic responses to concentrations of boron that are well within the range of concentrations occurring in geothermal waters.

BROMINE

Elemental bromine (Br) is soluble in water and has been measured in geothermal waters in concentrations ranging from 0 to 3.0 ppm. It has similar properties to chlorine and, as such, can also be used as an antiseptic. There is little information regarding bromine toxicity to aquatic organisms. No information was found regarding bromine toxicity to plants.

Bromine proved lethal to Daphnia magna at 10 ppm in soft water, while 20 ppm was toxic to goldfish (McKee and Wolf 1963). Bromine has been shown to be accumulated in crayfish and freshwater fish in a study conducted by Woods et al. (1979). Crayfish living in waters containing greater than or equal to 0.001 ppm Br concentrated this element to 86 ppm (based on one animal), while two crayfish from waters containing between 0.1 to 0.28 ppm Br accumulated 134 and 165 ppm.

Several species of fish were shown to accumulate bromine as well, but in lower concentrations than crayfish. Fish from waters containing greater than or equal to 0.001 ppm accumulated 12 to 28 ppm, while fish from waters containing greater bromine levels accumulated from 29 to 54 ppm. This study did not discuss any toxic effects associated with this accumulation.

CADMIUM

Cadmium (Cd) is a trace constituent in the geothermal waters characterized in Task 1, occurring in concentrations of <0.002 to 0.1 ppm. In nature, it occurs principally as a sulfide salt, frequently in association with lead and zinc. At lower soil pH, it is more readily available for uptake by plants. Cadmium concentrations in normal soils range from 0.01 ppm to 7.0 ppm (Dvorak and Lewis 1978).

Flora

Concentrations of 0.05 ppm cadmium or less are recommended for short-term irrigation use on sandy soil. For continuous use, levels of 0.005 ppm or less are recommended (Geonomics, Inc. 1978). Reduced crop yields have been reported with cadmium concentrations of 1.0 ppm (U.S. Environmental Protection Agency 1976).

Plant tissue normally contains up to 1 mg cadmium per kg tissue, but it is not essential for growth. Translocation can occur, with the effects of toxicity appearing in leaves (wilting and chlorosis) before growth is retarded (Salisbury and Ross 1969).

Saltwater cordgrass was not affected by 100 ppm cadmium and contained as much as 94 ppm after 8 weeks of exposure. Highest cadmium concentrations were found in below-ground parts. This species is able to concentrate cadmium several times the highest concentrations found in nature.

Sedge and alkali bulrush have the capacity to take up cadmium from the soils. Sedge translocates cadmium rapidly, while alkali bulrush concentrates it in the roots and lower stems. Brackish water marsh plants (salt cordgrass, bulrush, tule, saltgrass, and arrowgrass) have the ability to take up cadmium and concentrate it to an average of 74 ppm in their tissues. Bulrush, tule, and saltgrass translocate more cadmium from roots than do salt cordgrass or arrowgrass. Brackish water marsh species appear to take up and accumulate more cadmium than do freshwater marsh species. Saltwater cordgrass and cordgrass, both considered saltmarsh species, accumulate cadmium in roots but do not translocate large amounts to plant tops. Tissues averaged 152 ppm cadmium, indicating that saltmarsh species can absorb more cadmium than fresh or brackish water marsh species (Lee et al. 1976).

Water hyacinths have the capacity to absorb, translocate and metabolize, or concentrate a wide range of compounds. In laboratory studies, hyacinths have been shown to remove cadmium from solution at the rate of 0.67 mg per gram of dry plant weight per day. This species is expected to have the field capacity of removing 0.161 kg per acre per day when harvested daily. No toxic levels have been found for this species (Seidel 1976).

Soybean, often used as a forage for waterfowl, has a low tolerance of cadmium. Low concentrations retard seedling growth, inhibit trifoliate leaves, reduce dry weight (productivity), and produce progressive chlorosis with increasing concentrations of cadmium throughout the plant (Cunningham 1975). Other forage species (such as sorghum, sudan, and corn) exhibit higher concentrations of cadmium when grown on polluted soils. Concentrations decreased in plant tissue over time.

Legume crop production was reduced by 25% with the addition of 0.10 ppm cadmium in solution. Barley, farmed on several waterfowl production areas, experienced 20 to 50% reduction of yield when grown on cadmium-polluted soils (McKee and Wolf 1963).

Cadmium is accumulated through the food chain in sufficient quantities to be harmful to higher trophic levels, including humans (Thomann et al. 1974). Only if the cadmium to zinc ratios are carefully managed can the uptake of cadmium be controlled. An average ratio of 1:100 prevents accumulation in plants by limiting uptake. Organic matter in the soil complexes with cadmium through cation exchange, thereby limiting its availability for uptake by plant species. Concentrations of calcium, phosphorus, potassium, and aluminum in the soil can also affect cadmium uptake (McKee and Wolf 1963).

Fauna

Immobilization bioassays conducted on Daphnia magna indicate that 0.0026 ppm of cadmium chloride was the threshold level at 25° C (McKee and Wolf 1963). Daphnia had a 3-week LC_{50} of 0.005 ppm and experienced a 16% reduction in productivity after 3 weeks' exposure to 0.0017 ppm. Distress symptoms in the freshwater snail Australorbis glabratus were caused by 0.05 to 0.1 ppm Cd. The mayfly Ephemerella subvaria had a 96-hour LC_{50} of 2.0 ppm, while the mud crab Eurypanopeus depressus had a 72-hour LC_{50} of 4.9 ppm (Dvorak and Lewis 1978). During that same study, 11.0 ppm was the 100% lethal concentration for Eurypanopeus. In soft water, the midge Tanytarsus dissimilis had a 10-day LC_{50} of 0.0034 ppm but showed no effects in 0.0019 ppmcd.

Warmwater fish species listed by Dvorak and Lewis (1978) that have been used in cadmium bioassay studies include bluegill, green sunfish, fathead minnow, and common guppy. In one study the adult bluegill 11-month LC_{50} was 80 ppm, while for fry, the 96-hour LC_{50} was 1.94 ppm. The 96-hour LC_{50} for green sunfish fry was 2.84 ppm. The 96-hour LC_{50} for fry of the common guppy was reported to be 1.27 ppm cadmium. A 30-day LC_{50} for the fathead minnow was measured at 0.029 ppm (Dvorak and Lewis 1978). Channel catfish showed toxic effects at 0.017 ppm, but none at 0.012 ppm (U.S. Environmental Protection Agency 1976).

U.S. Environmental Protection Agency (1976) cadmium criteria take into account the fact that Cd toxicity increases in decreasing pH and set different criteria for soft and hard water. The soft water criterion for cladocerans and salmonids is 0.0004 ppm; for less sensitive species, it is 0.004 ppm. The hard water criterion for the sensitive organisms is 0.0012 ppm and for the less sensitive species is 0.012 ppm.

Cadmium has been shown to have a toxic effect on a variety of birds and mammals, including mallard ducks. The known effects on ducks are all sublethal, primarily affecting the kidneys, testes, and egg production. However, studies by White and Finley (1978a and b) and White et al. (1978) show that no weight loss or mortality occurred in mallards fed concentrations of cadmium up to 200 parts per million (ppm). The livers and kidneys accumulated the highest levels of cadmium. No histological anomalies appear in the livers despite high concentrations, but kidneys and testes both showed severe lesions, weight change, and apparent dysfunction after being fed concentrations of 200 ppm. Egg production was suppressed in ducks fed 200 ppm cadmium, but not in those fed lower concentrations. Thus, physiological effects are observed at 20 ppm, but do not become severe until 200 ppm. Accumulation in tissues is positively correlated with concentrations in the environment up to 20 ppm. At higher levels, the relationship diminishes, suggesting that the capacity of these organs to store cadmium is limited. Natural concentrations in the livers and kidneys of wild ducks are less than 10 ppm, but exceeded 100 ppm in birds fed 200 ppm. The toxic effects of cadmium are suppressed in the presence of zinc and iron for some species, but no information of this nature for waterfowl s available.

Cadmium levels in excess of 20 ppm in natural environments may generally reduce reproductive output of nesting waterfowl. More direct effects on individuals may occur as environmental levels approach 200 ppm.

CALCIUM

Calcium (Ca), in proper proportions, is essential for good soil condition. In normal soils, calcium and magnesium are the principal cations held by the soil in replaceable or exchangeable form. Calcium can easily replace sodium in the cation exchange complex and, therefore, has a tendency to counteract deleterious effects of sodium (Stout and Johnson 1957). Concentrations in geothermal effluent range from 0.28 to 320 ppm. At these levels, Ca can be beneficial to soils by improving texture (Dvorak and Lewis 1978).

Flora

Calcium is an essential macronutrient required for plant growth. A constant supply of calcium must be available for continued root growth. Calcium acts in enzymatic functions and in the formation of pectin, an insoluble substance which cements cell walls together. Deficiencies result in death or extreme distortion of growing cells (Salisbury and Ross 1969). Reports of studies investigating toxic concentrations of calcium were not found in the literature.

Concentrations of 5,000 ppm calcium in plant parts are not unusual. Leaves often contain 320 ppm calcium. Wheat, oats, and barley irrigated with geothermal effluent increased the percent calcium content found in grain compared with crops irrigated with "fresh" water. Calcium content of all freshwater irrigated crops averaged under 0.06 percent, while geothermally irrigated crops averaged 0.2 percent. No apparent injury was detectable (Schmidt and Spencer 1977). Calcium hypochlorite has been shown to be partially toxic to several species of bluegreen algae in concentrations of 2 ppm at 22.2° C (Becker and Thatcher 1973). Calcium ions, however, are not toxic.

Calcium has been implicated in the reduction of zinc uptake in barley. It may also elevate the toxicity of zinc that is already present in plants. The toxicity of magnesium, copper, and iron may be reduced by the presence of calcium. A zinc tolerant plant may gain additional tolerance to nickel and cadmium when calcium is present (Antonovics et al. 1971).

Fauna

Elemental calcium (Ca) is not found in most natural aquatic systems; rather, it occurs as calcium salts and ions. Although water hardness is caused by many ions dissolved in water, hardness is often equated to the concentration of calcium carbonate. Because many toxic trace metals are complexed and removed in hard water, increases in calcium content often enhance water quality. Calcium chloride and hydroxide are also present in addition to calcium carbonate and bicarbonate. These last two compounds have been most often used in bioassay studies.

The threshold concentration of calcium chloride ($CaCl_2$) for immobilization of _Daphnia magna_ was 920 ppm, while for immobilization of the two copepods _Cyclops vernalis_ and _Mesocyclops leukarti_, threshold concentrations of 1,730 ppm and 1,440 ppm, respectively, were required (McKee and Wolf 1963).

Warmwater fish species have even higher tolerances to calcium chloride, carbonate, sulfate, and nitrate than do invertebrates. Calcium hydroxide ($Ca(OH)_2$) is the most toxic of the compounds studied. While mosquitofish had

24-, 48-, and 96-hour TLm's of 56,000 ppm in $CaCO_3$ (Becker and Thatcher 1973), calcium hydroxide exhibited TLm values of 240 ppm in a 24-hour study, 220 ppm in a 48-hour study, and 160 ppm in a 96-hour study. Concentrations of calcium chloride that resulted in lethal toxic responses range from 2,775 ppm (2-4 day exposure of minnows) to 13,400 ppm (96-hour TLm of mosquitofish) (McKee and Wolf 1963).

CESIUM

Cesium (Cs) is a very reactive metal that forms salts similar to those of sodium and potassium. Cs has been measured in geothermal waters from 0.001 to 4.76 ppm. Until it was recognized as an important component of radioactive fallout, its toxicity to aquatic organisms was ignored. The literature available is predominantly concerned with the bioaccumulation of Cs-137 and Cs-134, which have been shown to be concentrated by a factor between 50 and 10,000 times by aquatic organisms (McKee and Wolf 1963). This naturally occurring element and its salts have been shown to react similarly to potassium; therefore, it is not considered to be very toxic.

CHROMIUM

Chromium (Cr) is an abundant element of the earth's crust. It exists in oxidation states of 2+, 3+, and 6+. It is found in soils principally as chromites, insoluble oxides that are unavailable at a pH over 4.0. The divalent form is readily oxidized, and the hexavalent form is unstable in soils and reduces to insoluble chromites. Soluble chromium almost always reverts back to insoluble forms. The concentration of chromium in soil averages 125 ppm. Serpentine soils contain much higher concentrations of chromium (Dvorak and Lewis 1978). Levels in the geothermal liquids identified in Task 1 are quite low (0.02 to 0.04 ppm).

Flora

Tolerance limits for irrigation water have been set between 5.0 and 20.0 ppm (Geonomics, Inc. 1978). Most plants take up small amounts of chromium, but there is no evidence that it is essential for growth. Generally, plants do not accumulate chromium, although plants growing on serpentine soils exhibit 3 to 10 times more chromium than plants grown on uncontaminated soils (McKee and Wolf 1963). Leafy vegetables that tend to accumulate iron also accumulate chromium, but not to toxic levels.

Species of cordgrass, saltgrass, arrowgrass, and bulrush grown hydroponically in varying concentrations of chromium exhibited the ability to accumulate this metal in the roots. Very little was translocated to aerial plant parts. Phosphorus and iron concentrations in the roots appeared to be closely associated with chromium accumulation and translocation (Lee et al. 1976).

At concentrations of 1.0 ppm, the unstable hexavalent chromium ion inhibits nitrogen fixation in soils. Chromium at 5 ppm in solution caused oats to become chlorotic; 15 and 50 ppm reduced growth rates. In algae, 0.139 ppm chromium produced a statistical decrease in production, while a tenfold increase in chromium produced a corresponding decrease in production. Algae have the capacity to concentrate radioactive chromium from its environs by a factor of 100 to 500. Chromium reacts synergistically with nickel (McKee and Wolf 1963; U.S. Environmental Protection Agency 1976).

Fauna

Aquatic invertebrates tested for hexavalent chromium toxicity include *Daphnia magna*, *Gammarus pulex*, midge fly larvae, and the snail *Polycelis nigra* (McKee and Wolf 1963; Dvorak and Lewis 1978). The toxic threshold for *Daphnia* ranged from 0.016 to 0.51 ppm. Total mortality of *Gammarus* occurred in concentrations of 1.4 ppm. *Polycelis*' toxic threshold was at 148 ppm CrO_4. Exposure to 25 ppm of chromium was not toxic to midges.

Freshwater fish generally exhibit greater tolerance to hexavalent chromium (McKee and Wolf 1963). Toxicity levels for bluegills exposed to several different chromium compounds ranged from 50 to 300 ppm. Bluegills tolerated 45 ppm $K_2Cr_2O_7$ in hard water for 20 days. Goldfish toxicity levels ranged from 52 to 177 ppm. Largemouth bass 48-hour TLm was measured at 196 ppm, and their 80-hour TLm occurred at 94 ppm.

Several chromate and dichromate compounds were tested on mosquitofish in 96-hour TLm studies (McKee and Wolf 1963). The toxic concentrations of chromium from these compounds ranged from 56 to 135 ppm. Fathead minnows experienced reproductive impairment from exposure to 2 ppm chromium for 10 months.

Because of the sensitivity of invertebrates to chromium (as shown in *Daphnia* studies), as well as the potential fish population impairment resulting from this constituent, U.S. Environmental Protection Agency (1976) has set the criterion at 0.1 ppm for protection of freshwater aquatic life.

CHLORIDE IONS

The chloride ion (Cl^-) concentration in geothermal waters ranges from 0.5 to 5,400 ppm. This is the most abundant halogen and is most commonly found combined with sodium (NaCL).

Relatively high levels of chloride can be tolerated by freshwater aquatic life and even higher levels by marine species. Toxic responses in warmwater fish life have been reported by McKee and Wolf (1963) for concentrations ranging from 2,000 to 10,500 ppm. Because the chloride ion readily complexes with many elements, including metals, its effect on flora and fauna shows a large degree of variance.

COPPER

Copper (Cu) is found in concentrations ranging from 0.004 to 0.08 ppm in the geothermal sources identified in Task 1. It is tightly bound to soil colloids and is rarely leached out of the main rooting zone (Reuther 1957). Soluble complexing agents in the soil solution contribute to the mobility of copper in soils. The water-soluble copper sulfates are more mobile than sulfides. Copper complexes are more stable than other metals at a pH range of 7.0 to 8.0 (Dvorak and Lewis 1978). Copper content in normal soils ranges between 10 and 60 ppm, but can be as extreme as 10,000 ppm (Antonovics et al. 1971). The total content of copper in soils is between 2 and 100 times the amount of available copper (Dvorak and Lewis 1978).

Flora

Copper is an essential micronutrient (U.S. Environmental Protection Agency 1976). It is absorbed as a divalent cupric or monovalent cuprous ion, existing in plants primarily in the cupric form (Salisbury and Ross 1969). Copper is vital in the functioning of certain enzymes and essential in the synthesis of chlorophyll molecules (U.S. Environmental Protection Agency 1976). Normal content in plants varies between 5 and 15 ppm, but higher concentrations can be found (Antonovics et al. 1971).

Roots are the primary storage site for copper, with high concentrations also found in chloroplasts (Reuther 1957). Copper uptake is regulated by an internal mechanism for tolerance. At low soil concentrations, copper uptake in above-ground parts is low. As soils increase in concentrations, uptake remains low until a threshold concentration is reached and uptake increases abruptly. The threshold concentration of copper in soils is different for each species.

Several plant species are considered indicator species for copper soils. These plants can tolerate extreme concentrations of copper. A pink is found in areas where soils contain 10,000 ppm copper, but takes up only 20 ppm in its leaves. Goose tongue, however, can accumulate up to 6,000 ppm on highly concentrated soils without toxic effects. Horse-tail will tolerate slightly less copper content. A blue-green algal species, Cirosiphon, is an indicator of copper contaminated areas, as are a variety of blue-green algal genera (Antonovics et al. 1971).

Toxic levels of copper can cause reduced growth, chlorosis, and stunted root development. Iron concentrations become depressed and symptoms of iron deficiencies are produced. Toxic copper concentrations also interfere with the uptake of other heavy metals. Concentrations of more than 400 ppm copper in the topsoil are usually considered toxic (Reuther 1957).

Toxicity/tolerance levels vary widely among plant species. Agricultural plants exhibit toxic symptoms at concentrations as low as 0.1 ppm (Antonovics et al. 1971). This is lower than the recommended safe levels for irrigation water (0.2 to 5.0 ppm; Geonomics, Inc. 1978). Barley shows toxicity effects at 0.17 ppm to 0.20 ppm. At a tenfold decrease, copper is beneficial to barley. Root growth was stopped in legumes at 1 ppm and chlorosis was produced in oats at 2 ppm copper (McKee and Wolf 1963).

Crops grown using geothermal effluent as irrigation water had copper concentrations well within the range of a comparison source for freshwater irrigated plants (Schmidtt and Spencer 1977) (Table B-2.)

Table B-2. Copper concentration of geothermal crops as compared to a range of concentrations for freshwater crops (ppm).

Crop	Comparison source	Geothermal crop
Barley	1.3-20	4.0
Oats	2.4-25.8	3.0
Wheat	1.1-16.8	4.0
Alfalfa	4.4-37.9	10.5

Various submergent plants (water weed, water milfoil, pickerelweed, pondweed, and a blue-green alga) are unaffected by copper concentrations of 10 ppm at pH 8.1 (Becker and Thatcher 1973). Water hyacinths grown in a solution containing 0.25 ppm copper accumulated a 41-ppm concentration in roots. At 16 ppm copper in solution, a linear increase in copper concentration in roots (14,801 ppm) was observed (Duffer and Moyer 1978).

Many blue-green algal species can tolerate high copper concentrations as long as conditions remain aerobic (Becker and Thatcher 1973). Many emergent marsh species are able to absorb and accumulate copper from soil solution. Bulrush, sedge, iris, cattail, and reed absorb concentrations of 4.8, 5.6, 5.7, 4.7, and 4.2 mg copper per kg dry weight, respectively (Lee et al. 1976).

Although copper can accumulate to high levels in plant tissue, no indication of bioaccumulation has been noted.

Copper produces synergistic effects in combination with zinc, mercury, chlorine, and cadmium (McKee and Wolf 1963). Antagonistic effects are related to increasing levels of water hardness.

Fauna

Pest aquatic invertebrates have been controlled through the use of copper compounds, such as copper chloride and sulfate, in concentrations ranging from 0 01 to 20 ppm. In copper chloride bioassay tests on *Daphnia magna*, their immobilization threshold concentration ranged from 0.027 to 0.096 ppm. Acute and chronic bioassays were conducted on *Gammarus*, *Physa*, and *Campeloma* in soft water (Arthur and Leonard 1970). Average 96-hour LC_{50} values for these species were 0.02, 0.039, and 1.7 ppm, respectively. *Gammarus* also showed a reduction in reproduction after 5 weeks' exposure to 0.012 and 0.006 ppm Cu. In other copper bioassay studies, the threshold concentration for the copepod *Cyclops vernalis* was 2.7 ppm, for *Mesocyclops leuckarti* 1.9 ppm, and for *Diaptomus oregonensis* 0.0024 ppm. *Cricotopus bicinctus* was found in a Michigan river in waters containing 2.2 ppm Cu; no other common benthic invertebrate was present (McKee and Wolf 1963). Other aquatic fauna exhibiting higher Cu tolerances are crayfish (*Orconectes resticus* - 96-hour LC_{50} of 3 ppm), stonefly (*Acroneuria lycomas* - 96-hour LC_{50} of 8.3 ppm), and caddisfly (*Hydropsyche betteri* - 14-day LC_{50} of 32 ppm). A study conducted to examine the effect of copper precipitate on benthic organisms in a lake with copper sulfate algae control concluded that 9,000 ppm was the toxicity limit of copper in mud for the midge *Tendipides plumosus* and the fingernail clam *Pisidium idahoense* (U.S. Environmental Protection Agency 1976).

Many warmwater fish species have low tolerance to copper. Goldfish have shown lethal effects at 0.009 ppm and at 0.036 ppm (96-hour LC_{50}). Bluegill sunfish responded negatively to 0.66 ppm (96-hour LC_{50}; Dvorak and Lewis 1978) and to 1.25 ppm (96-hour TLm; McKee and Wolfe 1963). Chronic effects were reported for bluegills after 22-month exposure to 0.162 ppm Cu (Benoit 1975). Fathead minnows have exhibited the lowest tolerance level for fish during a chronic study, conducted for 10 months, that showed reproductive impairment from exposure to 0.018 ppm. This species' 96-hour LC_{50} studies showed 0.023 and 0.075 ppm to be the lethal levels.

U.S. Environmental Protection Agency (1976) recommends a criterion of 0.1 times the 96-hour LC_{50}, as determined through a nonaerated bioassay using a sensitive aquatic resident species for protection of aquatic life.

FLUORINE

Fluorine (F) is one of the most reactive nonmetals and, as such, is rarely found in its natural state. It is normally found as a fluoride constituent in sedimentary or igneous rocks. Fluorine has been found in geothermal liquids in concentrations ranging from 0 to 24 ppm.

Fluorides found in soils are tightly bound and usually insoluble. As soil pH decreases, solubility of fluorides increases. Soil fluorides are widely distributed throughout the soil horizon, with increasing concentrations at increasing depth (Dvorak and Lewis 1978). Fluoride content typically varies from 10 to 1,000 ppm (average 200 ppm), with contaminated areas exhibiting greater concentrations. Soils derived from phosphates may contain 8,000 ppm fluoride (Bear 1957). Compounds are generally long-lived and not biodegradable.

Flora

Limits on the concentration of fluoride in irrigation water have not been established. Insolubility of fluoride and its apparent lack of detrimental effects on plants have been cited as the rationale (McKee and Wolf 1963). Uptake of fluorides from the soil is restricted, and plants rarely contain concentrations greater than 20 ppm.

Concentrations of fluorides between 10 and 1,000 ppm have no apparent detrimental effect on plants (McKee and Wolfe 1963). Crops of oats, wheat, barley, and alfalfa irrigated with geothermal effluent show no excessive accumulation of fluoride. The highest concentration (19 ppm fluoride) found in wheat was still considered safe for livestock feed. When compared with crops irrigated with "fresh" water, geothermal crops did not contain significantly higher concentrations of fluorides (Schmitt and Spencer 1977).

Gaseous and particulate fluorides pose a greater hazard to vegetation than soil fluorides. Airborne fluorides can enter leaves directly, where they tend to accumulate. The concentration is usually much greater in these localized areas than in the total plant (Dvorak and Lewis 1978).

Fauna

Studies utilizing herbivores indicate fluoride may be accumulated throughout the food chain. Plants can tolerate several times the concentrations that are toxic to animals. A potential biohazard exists with airborne fluorides as well as soil fluorides.

Fluorine levels found in Task 1 do not approach any toxicity levels for aquatic life. Daphnia has a 2-day threshold of immobilization of 270 ppm NaF. The 96-hour TLm of mosquitofish was measured at 419 ppm (McKee and Wolf 1963). Fluorine should not be toxic at the levels identified in Task 1.

HEAVY METALS

Interactions between heavy metals and plants are complex. The relative toxicity of heavy metals is influenced by environmental factors such as pH, alkalinity, oxygen and carbon dioxide concentration, salinity, temperature, precipitation, sedimentation, turnover rate, and ionic form (D'Itri 1977). Factors that confer resistance of toxicity to plants include age, life history stage, exposure, genetic complement, and physiological condition (Antonovics et al. 1971). The number of potential synergistic or antagonistic reactions possible among chemical compounds exponentially increases the possible effects of heavy metals.

The position and ionic state of metals in soils are important with respect to availability to and uptake by root systems. The absorption of a metal is completely dependent on ionic form. Ionic form often changes as leaching takes place (de la Cruz 1978), causing differential accumulation in the soil profile. Some metals such as zinc, copper, lead, and cadmium are available only in the top 30 to 40 cm of soil while others are available throughout the soil profile (D'Itri 1977).

Some plants have the ability to selectively accumulate metals, regardless of the concentrations found in soils. High plant tissue concentrations may be accumulated at low soil concentrations; conversely, soil concentrations may be exceedingly high with only normal levels found in plant tissues. Insufficient uptake of a necessary nutrient can damage physiological mechanisms as much as toxic quantities can interfere with the normal metabolic reactions in plants.

Heavy metals can be precipitated by organic humus in saline environments and become unavailable for uptake. Iron, for example, decreases exponentially with increasing salinity, as does manganese. This is due to flocculation and precipitation of iron. Iron precipitation can also be an effective influence on precipitation of other metals (Windom 1976).

Concentrations of available heavy metals vary between fresh and saline water, hard or soft water, and acidic or alkaline water. Moisture regimes of soils also influence toxicity of heavy metals. Moist soils are usually less toxic than drier soils because the effective concentration of metals around the roots is diluted (Antonovics et al. 1971).

Mechanisms of tolerance to heavy metals are diverse. Genetic plasticity is responsible for the evolution of metal tolerant races. This is very metal specific, but species tolerant to one metal are usually more tolerant to others (Antonovics et al. 1971). Some plants accumulate and store metals in cell walls or nonliving tissue; some complex organic nutrients to the metal and transport it through plasm to store in vacuoles (Ernst 1975); and some simply do not take up or accumulate metals.

It is evident from the above discussion that no simple statements can be made about heavy metal interactions. Many factors contribute to the effects of heavy metals on plant life. The same is true of otner elements and compounds for both plant and animal life in terrestrial and aquatic environments.

Thus, there are no simple answers to be gained from examination of the tabulated data; however, these data do provide a useful overview of trends in chemical constituents of geothermal wastes versus approximate toxicity levels.

HYDROGEN SULFIDE

Hydrogen sulfide (H_2S) is an extremely toxic compound, soluble in water, and reported to be found in geothermal liquids in concentrations ranging from 0 to 7.4 ppm. No data were found on levels toxic to vegetation. Hydrogen sulfide in waters with low oxygen content has been reported to be more toxic to aquatic invertebrates than waters with high oxygen content. Additionally, H_2S accumulates in low oxygenated waters and soils, thereby creating habitats which few organisms can tolerate.

Oseid and Smith (1974) found that 96-hour LC_{50} concentrations ranged from 0.059 ppm for the amphipod Gammarus pseudolimnaeus to 1.07 ppm for the isopod Asellus militaris. Based on chronic exposure tests, these authors suggest that no-effect levels are between 8 and 12% of a 96-hour LC_{50} test conducted to approximate, as closely as possible, the test organism's natural habitat conditions. This is especially important in burrowing organisms. In a physiological study made on the effect of H_2S on feeding habits, feeding was reduced in Gammarus when exposed to H_2S levels ranging from 0.01 to 0.05 ppm. Other studies list the minimum lethal concentrations for H_2S to be 1.0 ppm for Daphnia magna and mayfly larvae (McKee and Wolf 1963).

Freshwater fish have similar H_2S tolerance levels to those exhibited by aquatic invertebrates in the Oseid and Smith study. U.S. Environmental Protection Agency (1976) has concluded that 0.002 ppm is a safe level for walleyes, fathead minnows, and bluegill sunfish.

IODINE

Iodine (I) is generally found in very small quantities, primarily in sea water. It is relatively less reactive than the other halogens (e.g., chlorine and bromine). It has been found in geothermal waters in concentrations ranging from 0 to 0.24 ppm. Little information is available on the toxicity of this element, although in its molecular form it is a known antiseptic agent. In the literature survey conducted by McKee and Wolf (1963), 28.5 ppm iodine was found to be lethal to goldfish and minnows. Iodine is not considered an important toxicant in geothermal waters.

IRON

Iron (Fe) is the fourth most abundant element found in soils and is a major constituent of clays. It exists in the ferrous state in acidic soils. Organic matter increases the solubility of iron. In alkaline soils, iron may be so tightly bound that symptoms of deficiency may develop in the vegetation even though high concentrations exist in the soils. Iron content of soils averages 4% (Dvorak and Lewis 1978). Concentrations in the geothermal fluids identified in Task 1 range from 0 to 76 ppm.

Flora

An essential element for plant nutrition, iron aids in the formation of chlorophyll molecules. Deficiencies are indicated by yellow-white tissue, caused by the lack of chlorophyll. Plants normally require an average of 100 ppm iron in leaves (Salisbury and Ross 1969).

Crops irrigated with geothermal effluent averaged 100 to 220 ppm iron content. No appreciable difference in iron content was found between crops irrigated with geothermal water and crops irrigated with "fresh" water. Some experimental plots produced plants with an iron concentration lower in geothermal crops than "freshwater" crops (Schmitt and Spencer 1977). This could be attributed to the complex interactions of iron with other heavy metals.

Emergent marsh vegetation has demonstrated the ability to absorb iron from its habitat. Bulrush, sedge, cattail, and reed absorb quantities of iron at 0.79, 3.8, 1.1, and 0.92 mg iron per kg dry weight, respectively (Lee et al. 1976).

Data were not found on toxic concentrations of iron to vegetation. The presence of copper, manganese, zinc, or nickel may induce iron deficiencies. Iron may confer protection to toxic concentrations of copper (Antonovics et al. 1971).

Fauna

In well-aerated waters, iron oxidizes and precipitates out of solution. Because iron oxides are so insoluble, little toxicity testing has been done. The flocs of iron could be detrimental to both fish and other aquatic life forms (U.S. Environmental Protection Agency 1976). The U.S. Environmental Protection Agency (1976) has set the iron criterion at 1.0 ppm, although the data EPA presents showed toxicity occurred well below that level. They cite a study of mayflies, stoneflies, and caddisflies that found 0.32 ppm Fe to be the 96-hour LC_{50}. In another study of Fe toxicity, 0.9 ppm was toxic to carp in waters having pH of 5.5.

LEAD

Lead (Pb) exists in nature mainly as lead sulfide and other soluble lead salts. It has been found in study area geothermal liquids in concentrations ranging from 0.003 to 0.07. Most soil lead is unavailable for uptake by plants (only 0.003 to 0.005% of the total lead in soil is available). It is strongly fixed by the humic fraction of the soil, influenced more by cation exchange than soil pH (U.S. Environmental Protection Agency 1976; Dvorak and Lewis 1978). The usual concentration range of lead in soil is between 2 and 200 ppm, but can be greater due to pollution from road fallout, industrial discharge, or ore deposits (Bear 1957).

Flora

Restrictive concentrations in irrigation water range between 5 and 20 ppm. Inorganic lead salt buildup from irrigation water can be toxic to crops (Geonomics, Inc. 1978).

Lead concentrations in plants normally range between 3 and 4 ppm. Apparently 50 ppm is an upper tolerance limit for most vascular plants. No sublethal effects of toxicity are noticeable, but death occurs after 50 ppm (Salisbury and Ross 1969; Antonovics et al. 1971).

Small quantities of lead added to the soil (2.0 mg/kg) act to increase the nitrogen content of legumes. Additionally, lead nitrates in concentrations of 1.5 to 25 ppm can stimulate growth. Sugar beets are tolerant of 51.8 ppm lead, but higher concentrations are injurious. Mustard germination and growth were retarded by concentrations of 345 to 1,380 ppm (McKee and Wolf 1963).

Barley, oats, and wheat irrigated with geothermal effluent at the Raft River experiment exhibited no statistical difference in ppm lead (of grain) than "freshwater" irrigated plants; all plants receiving geothermal water had concentrations between 3.0 and 4.0 ppm (Schmitt and Spencer 1977).

Vegetation growing on waste soils (considered to be contaminated by lead at concentrations of 20.1 ± 5.2 ppm to 35.0 ± 2.5 ppm) showed no signs of injury and no visible differentiation from vegetation grown on control sites. The average concentration of lead in alfalfa at the control site was 2.2 ± 0.7 ppm, while on waste soils the concentrations of lead in plant tissues averaged 3.2 ± 0.8 ppm (Hutchison and Wai 1979).

Lead uptake is constant with increasing levels of soil lead until a point is reached when uptake becomes unrestricted and rises abruptly. Species can rarely tolerate conditions above the level at which there is a sudden increase in lead uptake (Antonovics et al. 1971).

Phosphorus and calcium are known to have antagonistic effects on lead toxicity (Lee et al. 1976). Lead and cadmium exchange synergistic and antagonistic effects. When lead concentrations are lower than cadmium concentrations, the toxicity of cadmium is increased. When concentrations of lead are greater than cadmium, toxicity is decreased. Lead and arsenic also react synergistically (Antonovics et al. 1971).

Fauna

Aquatic fauna can take up lead through the food chain or by absorption through the body surface. Lead is less toxic in hard water because it readily precipitates out of solution. The toxic effects of 1.0 ppm of lead have been shown to be destroyed by 50 ppm of calcium (McKee and Wolf 1963). Most lead is found in bottom sediments because it is slightly soluble and easily complexed. Consequently, benthic organisms may be affected more than planktonic or pelagic forms.

The planktonic *Daphnia* had a 48-hour LC_{50} of 0.48 ppm lead and a 3-week LC_{50} of 1.0 to 0.3 ppm. Insects with aquatic larval stages exhibited relatively high tolerances in a study review by Dvorak and Lewis (1978). The stonefly *Acroneuria lycorias* had a 14-day LC_{50} of 64 ppm; the mayfly *Ephemerello subvaria* had a 7-day LC_{50} of 16 ppm; and the caddisfly *Hydropsyche betteri* had a 7-day LC_{50} of 32 ppm. McKee and Wolf (1963) report that lower life forms, such as bacteria and flagellates, have much lower tolerance levels. The lethal concentrations for certain aerobic bacteria, organic feeding bacteria, and flagellates ranged from 0.1 to 1.0 ppm.

Tolerance of warmwater fish species to lead varies widely with water hardness. Studies conducted on fathead minnows in differing degrees of water hardness illustrate the antagonistic effect discussed previously. Softwater studies had a 96-hour LC_{50} of 2.4 ppm, while in one hard water study, the 96-hour LC_{50} reached 75.0 ppm (McKee and Wolf 1963).

U.S. Environmental Protection Agency (1976) has set water quality criteria at 0.01 times the 96-hour LC_{50} of the most sensitive organism present. This is due to the concentration effect and the possible transference of this toxicant through the food chain.

Lead poisoning in waterfowl has been recognized for many years. It has been estimated that 2 to 3% of all fall populations of waterfowl die of lead poisoning. The primary source is consumption of spent shot in heavily hunted areas as waterfowl pick up gravel and food. A number of studies have been conducted on toxic effects on ducks resulting from consumption of spent lead shot (Irwin and Karsted 1972; Dieter and Finley 1979; Koranda et al. 1979). These studies show that a single lead pellet (about 200 mg) can result in dysfunction of blood enzymes, brain tissue abnormalities, weight loss, and death. Consumption of greater quantities of lead accentuates these results. It was noted that ducks fed a high calcium diet survived high lead dosages, suggesting that calcium prevents the absorption of lead.

Studies of lead in normal diets were not uncovered. However, lead in contaminated vegetation was suggested as the cause of death in whistling swans found in northern Idaho (Benson et al. 1976). Concentrations of lead in tissues from these birds were similar to those in experimental mortalities. The lack of data regarding toxic levels of lead in a potential wetlands precludes recommending maximum concentration criteria for waterfowl.

LITHIUM

Lithium (Li) is one of the rarer alkali metals and has been found in geothermal waters in concentrations ranging from 0.01 to 20 ppm.

Suter (1978) reported that 2.6 ppm Li are toxic to aquatic organisms; however, more information is needed to fully assess the toxicity of this element to aquatic marsh species.

MAGNESIUM

Magnesium (Mg), a common element of soils, is widely distributed and found in high concentrations on serpentine areas (Stout and Johnson 1957). Its concentration in the geothermal fluids studied ranges from 0 to 73 ppm. Magnesium salts are extremely soluble at neutral pH, but can be available in high concentrations even when pH dictates low solubility. Magnesium, along with calcium cations, helps keep soils permeable (McKee and Wolf 1963).

Flora

Magnesium is an essential element for plant growth. It forms the center of the chlorophyll molecule and is therefore vital for photosynthesis (Salisbury and Ross 1969). Values up to 25 ppm are considered harmless to plants, soil conditions, and underground water systems (McKee and Wolf 1963). Wheat, oats, and barley irrigated with geothermal effluent experienced no statistical increase in percentage magnesium in grain analysis, compared with "freshwater" irrigated plants. Grasses, alfalfa, and potatoes contained high concentrations of magnesium (between 1,300 and 1,700 ppm), both in freshwater and geothermal crops (Schmitt and Spencer 1977). Bulrush, sedge, cattail, and reed absorb magnesium at rates between 0.82 and 2.06 ppm dry weight (Seidel 1976).

High levels of magnesium interfere with boron and mercury poisoning in many plant species (Antonovics et al. 1971).

Fauna

Aquatic organisms are able to tolerate large quantities of magnesium. The sensitive flatworm, Polycelis nigra, exhibited toxic response to 400 ppm $MgCl_2$, while 2 days' exposure to concentrations ranging from 740 to 3,500 ppm $MgCl_2$ proved lethal to Daphnia magna (McKee and Wolf 1963).

McKee and Wolf (1963) report that fish had toxic responses to concentrations of $MgCl_2$ ranging from 100 to 400 ppm, but that they withstood 1,000 to 3,000 ppm of Mg for 2 to 11 days. The species tested was not mentioned.

Magnesium chloride, the most common magnesium compound, has not been shown to be toxic, under most circumstances, to warmwater fish species. The most sensitive species listed by McKee and Wolf (1963) is a "minnow," which showed toxic effects after exposure to 476 ppm. Magnesium chloride also is reported to decrease the toxicity of calcium and potassium chloride.

U.S. Environmental Protection Agency (1976) has set no criteria for this element. Magnesium should not pose toxicity problems at the levels found in the geothermal sources identified in Task 1.

MANGANESE

Manganese (Mn) occurs frequently in soils high in iron. It occurs in the geothermal fluids studied at 0 to 1.5 ppm. Manganese is relatively less toxic than other trace elements in soils. Toxic concentrations, rarely reached, can occur in very acidic or poorly aerated soils. Under these conditions the divalent ion is formed (Dvorak and Lewis 1978).

Flora

Plants absorb only the divalent, soluble manganese ion. It is stable in plant tissues and easily translocated (Salisbury and Ross 1969). Manganese performs a structural role in the chloroplast membrane. The highest concentrations of manganese in the plant are found in chlorophyll tissue (Sherman 1957). Recommended concentrations of manganese in irrigation waters range between 2.0 and 20.0 ppm (Geonomics, Inc. 1978). When applied to soils, most soluble manganese is oxidized and rendered unavailable.

Grain obtained from wheat, oats, and barley irrigated with geothermal effluent contained manganese concentrations of 35, 50, and 29 ppm, compared with freshwater crops (concentrations of 40, 50, and 20 ppm). Geothermal effluent had no effect on these crops, or on grass or alfalfa (Schmitt and Spencer 1977). Some plants can absorb high concentrations of manganese with no apparent toxicity. Bulrush can take up 1,200 mg manganese per kg dry weight without injury. Cattails perform similarly, absorbing 779 mg per kg from growth media. Water hyacinths absorbed 10 times the concentration of manganese from a contaminated lake than from a healthy lake (2,500 vs 250 mg/kg) (Seidel 1976).

Manganese exhibits synergistic effects in the presence of molybdenum, vanadium, or nitrates (McKee and Wolf 1963). Iron may intensify adverse effects of manganese because of the capacity of manganese to substitute for iron in compounds when excessive concentrations of manganese are present (Antonovics et al. 1971). Symptoms of injury due to toxic concentrations of manganese have been diminished by cobalt, aluminum, ammonium, and phosphate deficiency (McKee and Wolf 1963).

Fauna

Natural waters rarely contain more than 1.0 ppm of manganic or manganous ions (McKee and Wolf 1963). Geothermal liquids have been reported to contain concentrations ranging from 0 to 1.5 ppm. Manganese is thought to be bioaccumulated (Dvorak and Lewis 1978).

Invertebrates such as *Daphnia magna* and *Polycelis nigra* have shown a wide range of toxic reactions to manganese. *Polycelis* had a lethal threshold concentration of approximately 700 ppm (McKee and Wolf 1963), while *Daphnia* had a 3-week LC_{50} of 5.7 ppm (Dvorak and Lewis 1978). After exposure to 4.1 ppm Mn, *Daphnia* experienced 16% reproductive impairment. McKee and Wolf (1963) report that crustaceans, worms, and insect larvae tolerated 15 ppm Mn for 7 days.

There is little information regarding the tolerance of freshwater fish species to manganese. In one study, fingerling catfish tolerated 40 ppm Mn for 4 days. Carp, tench, and trout tolerated 15 ppm for 7 days (McKee and Wolf 1963). U.S. Environmental Protection Agency has not set water quality criteria for manganese.

MERCURY

Mercury is present in the geothermal effluent studied at concentrations of 0.00007 to 0.02 ppm. When applied to soil, it is rapidly fixed by organic matter, with some volatilization. Organic (methylated) mercury is the most toxic form. A biological mechanism as elucidated by Rodgers et al. (1978) exists that prevents the accumulation of methylmercury in soils. For this reason, levels of available mercury in the soil are low.

Flora

Mercury is neither essential nor beneficial to plants. It can be absorbed (when soluble in soil solution) and translocated to leaves, but this rarely occurs. Duckweed can accumulate high concentrations of mercury by surface adsorption without injury (U.S. Environmental Protection Agency 1976). This could present a hazard due to bioconcentration through the food chain (Young 1974).

Fauna

Mercury has been shown to be toxic to aquatic life at concentrations as low as 0.0001 ppm. As noted above, mercury is more toxic in the organic form (methylmercury) than it is in the inorganic state. The methylation process occurs through bacterial processes, through ingestion and complexing in animal tissues, or in natural sediment processes. It is especially common under anaerobic conditions. In addition to its highly toxic nature, mercury is also known to biomagnify in animal tissues (3,000 or more times over ambient concentrations), and has synergistic effects with other trace elements, such as copper.

Anderson (1948) reported the threshold for immobilization for *Daphnia magna* to be less than 0.006 ppm, while in a study reviewed by Dvorak and Lewis (1978), *Daphnia* had a 3-week LC_{50} of 0.13 ppm Hg.

U.S. Environmental Protection Agency (1976) reported that 0.04 ppm of methylmercuric chloride adversely affected *Daphnia*. Rehwoldt et al. (1973) studied oligochaetes, *Gammarus* sp., Tricoptera, Zygoptera, *Chironomous* sp., and *Amnicola* sp. (both adults and eggs). They found the most sensitive organism to be *Gammarus*, with a toxic threshold at 0.01 ppm. The least sensitive species was the adult snail, *Amnicola* sp. with a threshold level of 2.1 ppm. Vernberg and Vernberg (1974) studied the synergistic effects of mercury on fiddler crabs in relation to changes in salinity and temperature. They found that mercury was more toxic at low temperatures and low salinity than at high temperature and low salinity.

Among the warmwater fish species studied, the most sensitive reported is the fathead minnow (McKee and Wolf 1963). During a 6- to 8-week study, 0.2 ppm Hg was the lethal dose for this species. In another fathead minnow study, detrimental effects were noted at 0.12 ppm, but none were seen at 0.07 ppm.

Along with immediate toxic effects, organisms also accumulate mercury in their tissues and transport it into the food chain. In a study of new impoundments in Illinois (Cox et al. 1979), largemouth bass contained more mercury in their tissues than bluegills, a prey species. This study also indicated that new impoundments leached mercury from the lake bottom sediments and, during approximately the first 5 years, fish may contain higher levels of mercury than the level approved as safe (0.5 ppm) by the U.S. Food and Drug Administration.

Because of its high toxicity and biomagnification capabilities, U.S. Environmental Protection Agency (1976) has set the criterion at 0.05 ppm Hg to protect freshwater aquatic life. Selenium has been reported to have antagonistic effects against the toxic properties of some mercury compounds (Dvorak and Lewis 1978).

Mercury residues have been found in a number of wildlife species (Dustman et al. 1972; Stendall et al. 1976). Toxic effects have been recorded for several bird species including starlings, common grackles, red-winged blackbirds, brown-headed cowbirds, and Japanese quail (Hill and Shaffner 1976; Hill and Soares 1977; Finley et al. 1979). Intensive studies of mercury toxicity have also been conducted on mallards (Heinz 1974, 1975; Heinz and Locke 1976; Heinz 1976a, 1976b; Stickel et al. 1977; Heinz 1979) and black ducks (Finley and Stendall 1978). In studies of more than three generations of mallards, Heinz (1979) has shown that methylmercury fed in concentrations as low as 0.5 ppm resulted in reduced reproductive output and altered behavior in young. This concentration is calculated to be the equivalent of 0.1 ppm in a wild diet. Hens laid fewer total eggs than controls, more eggs were laid outside their nest boxes, and hatching success was reduced. Ducklings of mercury-fed adults responded more slowly to maternal calls and showed hyperresponsive reactions to fright stimuli.

In similar studies, Heinz and Locke (1976) showed that ducklings of adult mallards fed 3 ppm had reduced survival, compared with controls. Histological analysis of these ducklings revealed extensive brain lesions that were believed to be caused by high concentrations of mercury in the eggs (5 to 7 ppm). Similar concentrations were also found in brain tissues of the ducklings. In addition to accumulation in the brain, studies by Stickel et al. (1977) suggest mercury rapidly accumulates in kidney and liver tissues and is retained for periods up to 16 weeks. Investigations on black ducks (Finley and Stendall 1978) showed toxic effects and accumulations similar to mallards.

While the studies suggest significant impacts on reproduction, data were not found showing toxic effects of mercury on other physiological or behavioral functions in adult waterfowl. Nevertheless, it would appear that environmental concentrations of 0.1 ppm or greater would have significant detrimental effects on waterfowl population dynamics. Because of the bioaccumulation potential of mercury, levels below 0.1 ppm may also result in reduced reproduction in waterfowl. The definition of the lower threshold level must be determined by further research.

MOLYBDENUM

Molybdenum (Mo) occurs in minor concentrations (0.003 to 0.02) in the geothermal effluents studied. It is present in some soils, but not widely distributed. Oxidized molybdates are the most common molybdenum compounds in soils. It is fairly mobile in alkaline soils, but decreases in availability as pH decreases (Dvorak and Lewis 1978). Concentrations found in soils generally range from 1 to 3 ppm, but can be as high as 75 ppm (Stout and Johnson 1957).

Flora

An essential element in plant nutrition, molybdenum functions in nitrogen fixation and transfer processes in plants. Deficiencies commonly result in "whiptail" disease (twisted, chlorotic leaves), which results in decreased productivity (Salisbury and Ross 1969). Normal accumulation in plants ranges between 5 and 20 ppm, but concentrations of 100 ppm without toxic effects are not uncommon (Stout and Johnson 1957). Molybdenum concentrations are generally highest in legumes, especially those plants grown on poorly drained soils (Dvorak and Lewis 1978). Oats normally contain concentrations of 0.4 ppm but can tolerate molybdenum as high as 200 ppm with limited toxicity (McKee and Wolf 1963).

Caution should be used with forage crops grown in the presence of excessive amounts of molybdenum. Molybdenum is poisonous to livestock at levels as low as 5 ppm, producing a deficiency of copper (Dvorak and Lewis 1978).

Several algal species are capable of concentrating molybdenum as much as 15 times the concentration of levels found in water.

Symptoms of toxicity are similar to selenium poisoning. Copper reduces symptoms of toxicity. Molybdenum acts to decrease deleterious effects of manganese, cobalt, and nickel poisoning (McKee and Wolf 1963).

NICKEL

Nickel (Ni) is one of the less reactive metals and has been found in study area geothermal fluids at <0.002 to 0.08 ppm. At most pH's above 7.0 and below 6.5, nickel is fixed in soils and not readily available (Dvorak and Lewis 1978). Concentrations in soils range between 10 and 40 ppm, but can be as high as 140 ppm on serpentine soils. Where nickel concentrations in soils are high, there seems to be a corresponding excess of magnesium and a limited supply of molybdenum (Bear 1957).

Flora

Nickel is normally toxic to plant life at very low concentrations. It interferes with the uptake of iron, producing symptoms of iron deficiencies (Dvorak and Lewis 1978). Sufficient levels of iron can reduce the toxicity of nickel, as will relatively high concentrations of molybdenum and phosphorus (Lee et al. 1976).

Nickel is not an essential element in plants, and is rarely found in tissue concentrations over 2 ppm. Aerial parts exhibit low levels, regardless of external levels (Antonovics et al. 1971). Levels of 29 ppm are toxic to oats; normal concentration of nickel in oats is 2 ppm (McKee and Wolf 1963). Several emergent marsh species can remove nickel from the environment at relatively high rates. Sedge can absorb 2.46 mg nickel per kg dry weight. Bulrush, cattail, and reed absorb 1.71, 1.83, and 1.53 mg/kg dry weight, respectively (Lee et al. 1976; Seidel 1976). *Villozia equisetoides* and *Dicoma macrocephala* exhibited uptake of nickel at concentrations of 1,000 ppm (Antonovics et al. 1971).

Nickel accumulates in the epidermis and sclerenchymatous tissue in plants--those tissues that are not living. This could be a storage mechanism to alleviate high toxic concentrations around living roots (Antonovics et al. 1971).

Fauna

This element is only moderately toxic to freshwater organisms (McKee and Wolf 1963). Toxicity depends on species, pH, and synergistic effects (U.S. Environmental Protection Agency 1976).

Daphnia had a 48-hour LC_{50} of 0.51 ppm Ni and showed 16% reproductive impairment after 3-week exposure to 0.03 ppm. The mayfly Ephemerella subvaria had a 96-hour LC_{50} of 4.0 ppm, while the caddisfly, Hydropsyche betteri, had a LC_{50} of 64.0 ppm in less than 14 days. Fathead minnows, bluegills, and goldfish had 96-hour LC_{50}'s of 4.58, 5.18, and 9.82 ppm, respectively.

U.S. Environmental Protection Agency (1976) has set the water quality criterion at 0.01 times the 96-hour LC_{50} of the most sensitive species present to protect aquatic life from nickel toxicity.

NITRATE AND NITRITE

Nitrate (NO_3) occurs in geothermal liquids in concentrations ranging from 0 to 42.0 ppm. The nitrate radical is a major source of nitrogen for plants and can increase productivity in aquatic systems.

Fauna

The most toxic level reported by McKee and Wolf (1963) was 2670 ppm, the toxic threshold concentration of nitrate (as sodium nitrate) for the flatworm Polycelis nigra. Bluegill sunfish had a 96-hour LC_{50} of 420 ppm potassium nitrate and 2,000 ppm sodium nitrate.

Nitrite (NO_2), by comparison, is found in concentrations of 0 to 0.12 ppm, and is generally more toxic. The most toxic response to nitrite was exhibited by mosquitofish with 48- and 96-hour LC_{50}'s of 1.5 ppm NO_2. U.S. Environmental Protection Agency (1976) references a 1972 report by McCoy that recommends that nitrite levels remain below 5 ppm (and nitrate levels remain below 90 ppm) in order to protect warmwater species. No criterion was given because toxic nitrite levels are unlikely to occur in natural surface waters.

PHOSPHORUS:PHOSPHATES

Phosphates (PO_4) are compounds found in the geothermal liquids studied at 0.01 to 1.4 ppm. Phosphorus is relatively unavailable in most soils, as the solubility is low at normal soil pH. Soil microorganisms change organic phosphorus into inorganic phosphorus at increasing rates as pH increases. Therefore, acidic soils contain much greater quantities of organic phosphate. Phosphorus can be depleted in soils through plant uptake, the amount available depending on soil characteristics (Olsen and Fried 1957). Less phosphorus is removed from soils when only the grain is harvested from a crop rather than the entire plant (Keeney and Walsh 1975). Soils with abundant moisture supply have a greater concentration of soluble phosphorus. This is because of the dilution of cation concentrations in the soils (Olsen and Fried 1957).

Flora

Phosphorus is necessary for all plant processes. It is absorbed by plants as a monovalent or divalent ion and converted to the organic form after it enters the root and before the substance is translocated (Salisbury and Ross 1969). Phosphorus compounds are easily translocated and readily removed from old leaves when insufficient supplies are available for new leaves (Olsen and Fried 1957). Growth stops without available phosphorus. On the average, a terrestrial plant contains 2,000 ppm phosphorus (Salisbury and Ross 1969). Legumes possess the capacity to remove large amounts of phosphorus from soils. A possible mechanism for this ability is related to cation exchange. A high rate of exchange decreases the concentration of cations in the soil, increasing phosphorus solubility (Olsen and Fried 1957).

Analysis of crops irrigated with geothermal effluent indicated there was no statistical difference in phosphorus content over control crops irrigated with "fresh" water. All averaged 2,200 to 2,900 ppm phosphorus (Schmitt and Spencer 1977).

Bulrush can accumulate 2 mg phosphorus per kg dry weight from soils irrigated with polluted water. Other emergent species (sedge, cattail, and reed) absorb 2.2, 2.2, and 1.4 mg/kg dry weight, respectively (Lee et al. 1976). Submergent plants also have the capacity to absorb high concentrations of phosphorus. Pondweed, waterweed, and hornwort can remove 25% of the total phosphorus in a holding pond in 28 days with harvesting (Duffer and Moyer 1978).

Concentration of phosphorus appears to be detrimental only in standing water. Eutrophication is the usual result of high phosphorus concentrations. Aquatic vegetation, usually algae, can experience large biomass increases as a result of phosphorus additions, upsetting the balance in aquatic habitats (U.S. Environmental Protection Agency 1976).

Collectively, iron and phosphorus content of plants may influence the amounts of heavy metals taken up by plant roots. The phosphorus content of aerial parts was reduced in several emergent marsh species when they were grown in heavy metal contaminated solutions. Uptake and concentration of zinc and nickel were positively correlated with phosphorus content (Lee et al. 1976).

POTASSIUM

Potassium (K) is present in concentrations of 0.15 to 660 ppm in geothermal waters in the study area. In soils, potassium is relatively unavailable for uptake because of the insolubility of most of its compounds (Reitemeier 1957).

Flora

Potassium is essential for basic physiological functions, including sugar formation, translocation and synthesis of proteins, cell division, and growth (McKee and Wolf 1963). Although it is not involved in any structural function or permanent in organic molecules, it is bound tightly within the cell. Translocation from mature leaves to younger tissue can be accomplished. Deficiencies result in yellowing of leaf margins in older leaves, progressing to a general reduction in growth (Salisbury and Ross 1969).

Crops irrigated with geothermal effluent exhibited no variation in potassium levels from control crops grown with "fresh" water. Potassium concentrations averaged from 21,000 to 27,000 ppm in all crops grown during the experiment (Schmitt and Spencer 1977).

Common emergent vegetation has the ability to absorb potassium from polluted waters. Reed can accumulate 8.1 mg potassium per kg dry weight, while bulrush, cattail, and sedge absorb 10.3, 14.1, and 13.9 mg/kg, respectively (Lee et al. 1976). Data were not found on toxic levels of potassium to vegetation.

Potassium resembles sodium in many of its properties and can replace sodium salts in soils. In saline solution, potassium can limit the uptake of sodium chloride in plants (McKee and Wolf 1963). Soluble calcium depresses the supply of potassium to vegetation (Reitemeier 1957). Nitrogen and phosphorus, if present in large concentrations, can reduce potassium concentrations in plants, even though the available supply of potassium is high. In areas of high soil copper concentration, the greatest vegetative density is found where potassium concentrations are excessive (Antonovics et al. 1971).

Fauna

In aquatic systems, the toxicity of potassium is greater than calcium, manganese, and sodium and is decreased when combined in solution with calcium and sodium. The chemical species present is important in determining toxicity levels. The chloride form occurs most commonly and is the least toxic species. Potassium nitrate is the next least toxic form.

Potassium chloride and potassium nitrate toxicity levels were tested for the flatworm Polycelis nigra. This organism's threshold concentration was determined to be approximately 350 ppm for both chemical species (McKee and Wolf 1963). Other aquatic invertebrates tested for potassium toxicity levels included Gammaridae (lethal level of 200 ppm), Chironomidae (lethal level of 700 ppm), and Trichoptera larvae (lethal level of 1,000 ppm). The most sensitive invertebrate tested for threshold of immobilization due to KCl was the cladoceran Leptodora kindtii, which registered toxic response to 127 ppm. The copepod Diaptomus oregonensis was equally sensitive, being immobilized by 134 ppm KCl (McKee and Wolf 1963).

Several fish species have exhibited toxicity ranges between 50 and 200 ppm KCl or KNO^3 when tested in distilled water (McKee and Wolf 1963). For example, potassium chloride has been lethal to goldfish in concentrations of 74.6 ppm. Bluegills and mosquitofish have been tested as well and exhibit 96-hour LC_{50}'s of 2,010 and 920 ppm, respectively.

SELENIUM

Selenium (Se) is present in the geothermal sources identified in Task 1 in concentrations ranging from 0 to 0.014 ppm. It is found in soils as elemental selenium, basic ferric selenite, and calcium selenate (U.S. Environmental Protection Agency 1976). In acidic soils, insoluble ferric selenite is found, whereas calcium selenate is readily available in alkaline soils (Dvorak and Lewis 1978). Soils derived from Cretaceous rock are high in selenium, usually 5 to 80 ppm; however, most soils contain 1 ppm or less (Bear 1957; Dvorak and Lewis 1978).

Flora

Selenium is readily absorbed in high quantities in plants, apparently without injury. Indicator plants, those species that are characteristic of seleniferous soils (e.g., locoweed and saltbush), can accumulate up to 15,000 ppm selenium in aerial parts without showing signs of toxicity (Bear 1957). Any vegetation to be used as fodder for livestock should contain less than 5.0 ppm or acute selenium poisoning may develop (McKee and Wolf 1963). Irrigation water safety levels have been established as 0.05 ppm in order to prevent toxic accumulation in forage crops (Geonomics, Inc. 1978). Duckweed concentrates selenium, presenting hazards for accumulation in waterfowl (Rodgers et al. 1978).

Concentrations of selenium that can be tolerated by nonaccumulating plants vary from 5 to 300 ppm (Dvorak and Lewis 1978). Such variation is, no doubt, caused by different growth regimes.

Toxicity is indicated by reduced growth, which can be very subtle. Chlorosis or a darkening of chlorophyll are additional symptoms (Salisbury and Ross 1969). Crops irrigated with geothermal effluent waters experienced a decrease in selenium content when compared with control crops irrigated with freshwater. No detrimental effects were exhibited (Schmitt and Spencer 1977).

Selenium resembles sulfur in many properties and has competitive effects on sulfur metabolism. Some crop plants accumulate selenium in direct proportion to their sulfur requirements. High concentrations of sulfates diminish the uptake of selenium and act as a partial antidote to toxicity (McKee and Wolf 1963; Bear 1957). The explanation for this antagonistic effect lies in the fact that sulfur competes for reaction sites with selenium, rather than binding with the toxic metal (Antonovics et al. 1971).

Fauna

Selenium is a known carcinogen and teratogen, but has been shown to be antagonistic toward the carcinogenic and teratogenic properties of cadmium and arsenic. Selenium is antagonistic to mercury toxicity as well (Dvorak and Lewis 1978). Because it readily complexes out of solution, sediments normally contain higher levels of selenium than waters, thus exposing sediment feeding benthic organisms to greater levels of this toxicant.

Daphnia's 2-day threshold concentration has been measured at 2.5 ppm (U.S. Environmental Protection Agency 1976). Fathead minnows had a 96-hour LC_{50} of 2.9 ppm. Juvenile bluegills were the most tolerant, with a 96-hour LC_{50} of 40 ppm.

U.S. Environmental Protection Agency (1976) has set the recommended water quality criterion at 0.01 times the 96-hour LC_{50} of the most sensitive species.

SILVER

Silver is found in several ores such as argentite, hornblende and proustite. It can be leached into ground water or surface water, but quickly precipitates, as many of its salts (such as silver chloride, sulfide, and arsenate) are insoluble. Silver nitrate and sulfate, however, are relatively soluble and are considered toxic to aquatic life. The range of silver in geothermal sources is 0.004 to 0.02 ppm.

Fauna

McKee and Wolf (1963) report that *Daphnia*'s threshold effect occurred at 0.03 ppm of silver nitrate while the flatworm *Polycelis nigra*'s threshold concentration is reported to be 0.15 ppm of silver. The threshold for immobilization of *Daphnia* in Lake Erie water was measured at 0.0051 ppm silver nitrate.

Fish bioassays conducted on guppies and sticklebacks report very close agreement in lethal concentration levels. Guppies had an LC_{50} of 0.0043 ppm, while 0.003 ppm was the lethal concentration level for sticklebacks.

SODIUM

After chloride, sodium (Na) is one of the main components in most geothermal liquids, with concentrations ranging from 5.8 to 3,100 ppm. Although normally considered only as a factor in the total dissolved solids of effluents, sodium has a considerable influence on soils. Excessive amounts of sodium in alkaline soils cause saturated soil colloids to swell. This results in a reduction in drainage and aeration, further increasing pH. High concentrations of sodium are both deleterious to soils and toxic to plants (McKee and Wolf 1963).

Flora

Sodium is required in very limited amounts for plant nutrition. Toxicity levels vary widely among species, races, and ecotypes. No set limits can be determined for tolerance of sodium, except on an individual species basis. There is only one known plant species that requires excessive levels of sodium for growth (McKee and Wolf 1963; Salisbury and Ross 1969; Antonovics et al. 1971).

Sodium acts to limit soil water available for plant uptake, producing osmotic stress and retarding growth. Leaching with standing water is the most efficient means to reduce excessive sodium salts in soils (Stout and Johnson 1957).

Some emergent plants have the ability to remove sodium from solution. Cattails possess the greatest capacity, absorbing 12.2 mg/kg dry weight. Bulrush can accumulate 6.3 mg/kg, sedge 2.2 mg/kg and reed 1.1 mg/kg on a dry weight basis (Lee et al. 1976; Seidel 1976). Wheat, oats, barley, and alfalfa irrigated with geothermal effluent exhibited levels of sodium well within the range expected (Schmitt and Spencer 1977).

Halophytic algae have been found that will grow in sodium chloride concentrations greater than 3 molar. Algae have extremely wide tolerances for sodium. Studies have shown freshwater species of algae that grow well in 50% sea water (Levin 1960).

Sodium has the ability to substitute for potassium requirements in plants (Stout and Johnson 1957).

Fauna

The lowest concentration of sodium reported by McKee and Wolf (1963) to affect aquatic invertebrates is 1,000 ppm ($NaNo^3$), which was the toxicity threshold for the flatworm *Polycelis nigra*. Another study listed 2,100 ppm as the lowest immobilization threshold concentration for *Daphnia* and other fish food organisms. Warmwater fish species have similar toxicity thresholds.

SULFATES

Sulfates occur in natural waters as a result of leaching from gypsum and other common minerals. The geothermal liquids characterized in Task 1 contain from 2 to 4,520 ppm sulfate. Sodium, potassium, and ammonium sulfate are highly soluble and are among the major forms occurring in these waters.

Fauna

The lowest concentration reportedly toxic to aquatic invertebrates is 4,547 ppm $NaSO_4$, toxic to *Daphnia magna* after 100 hours. Shiners were reported to show toxic responses after exposure to 100 ppm $NaSO_4$ for 120 hours; however, most other fish species reported have toxicity thresholds and 96-hour LC_{50}'s ranging from 11,200 ppm $NaSO_4$ for minnows to 34,000 ppm $NaSO_4$ for mosquitofish (McKee and Wolf 1963).

Potassium sulfate can be more toxic to fish, as 869 ppm is reported to have killed bluegill sunfish and sticklebacks in 4 days.

TIN

Tin (Sn) has been reported to occur in geothermal liquids in concentrations ranging from less than 0.02 to less than 0.2 ppm. Trace amounts of this element are considered beneficial. Accelerated growth has been noted to occur in goldfish exposed to 0.6 ppm. Daphnia had a toxicity threshold of 25 ppm $SnCl_2$ and an immobilization threshold of 146 ppm. Because of these high toxicity levels and the low levels of tin found in geothermal fluids, this element should not present biological problems for wetland organisms.

TOTAL DISSOLVED SOLIDS

Total dissolved solids (TDS) can be a major constituent of geothermal waters. In the study area, the TDS range is from 119 to 85,000 ppm. Dissolved solids usually consist of carbonates, bicarbonates, chlorides, sulfates, phosphates, and nitrates in combination with sodium, potassium, calcium, and magnesium (McKee and Wolf 1963; U.S. Environmental Protection Agency 1976).

The term dissolved solids is not precisely equivalent to salinity, but considered equal for practical purposes (U.S. Environmental Protection Agency 1976). It has no real bearing on soils systems except in relation to individual components. Water used for irrigation has suggested limits for dissolved solids, depending on individual crops, due to the hazard of salinity buildup in soils. It is probably sufficient to say that a concentration of total dissolved solids of approximately 5,000 ppm is harmful to plant life. Freshwater aquatic organisms are usually tolerant of up to 2,500 to 5,000 ppm TDS (McKee and Wolf 1963). Components contributing to TDS are discussed individually throughout this Appendix.

VANADIUM

Vanadium (V) occurs as a trace constituent of some geothermal waters (Geonomics, Inc. 1978), but has not been reported from the sources characterized in Task 1. Its salts are usually soluble and remain in solution, not becoming fixed in soils (Dvorak and Lewis 1978). Occurrence in soils is relatively common, with concentrations as high as 470 ppm (McKee and Wolf 1963).

Flora

Vanadium poses no threat to plant life; small quantities may even be beneficial. Vegetation found on soils high in vanadium contained only approximately 10 ppm in tissues. Most vanadium was contained in roots, with very little (less than 1 ppm) translocated to aerial parts (Stout and Johnson 1957). Few data are available in the literature on either tolerance or toxic levels in plants. Water hyacinths have the capacity to remove 115 mg/kg vanadium from a polluted lake, compared with 6 mg/kg in a healthy lake (Seidel 1976). The algae Scenedesmus sp. actually requires high concentrations of vanadium for growth. This requirement could be due to the catalytic role of vanadium in the fixation of nitrogen (Stout and Johnson 1957).

Little hazard of accumulation through the food chain exists because of the limited transport of vanadium from roots to aerial parts (Dvorak and Lewis 1978).

Fauna

Vanadium has been shown to be an essential nutrient for a number of animals. However, excessive doses can have toxic effects and interfere with normal metabolic processes (White and Dieter 1978). Studies have determined that diets with 25 ppm depressed growth in young chickens and mortality resulted from diets with 200 ppm. Egg laying in chickens was reduced when fed 300 ppm vanadium, but not in quail. Little is known about the toxic effects of vanadium on waterfowl. However, a study by White and Dieter (1978) determined that concentrations up to 100 ppm in mallard diets had no effect on body weight and no deaths occurred. They found that vanadium accumulated in the bone and liver in relation to environmental concentrations. There was some evidence of altered lipid metabolism in some hens fed 100 ppm. Concentrations in the bones of hens were five times those found in drakes, suggesting a sex-linked mechanism of calcium mobilization. No effect on reproduction was observed.

Based on these very preliminary results, it appears that concentrations of vanadium in excess of 100 ppm may be detrimental to waterfowl and their long-term use of developed wetlands.

ZINC

Zinc (Zn) is most often found in acid soils, and occurs abundantly in rocks and ores. It has been measured in the geothermal fluids characterized in Task 1 in concentrations ranging from 0.005 to 2.32 ppm. There is some evidence that zinc ions are absorbed permanently in silt, resulting in inactivation of zinc. High pH reduces the availability of zinc due to the formation of insoluble zinc hydroxide. Soluble zinc salts complex with soil molecules, becoming unavailable for uptake by plants. Concentrations normally found in soils range between 0 and 100 ppm (Seatz and Jurinak 1957; McKee and Wolf 1963; U.S. Environmental Protection Agency 1976; Dvorak and Lewis 1978).

Flora

A linear relationship exists between the amount of zinc found in soils and its concentrations in plant tissue (Antonovics et al. 1971). In one study, vegetation growing on contaminated sites contained approximately four times the amount of zinc as the vegetation growing on control plots. It is recommended that irrigation waters contain 10 ppm zinc or less, due to the narrow margin between deficiency and toxicity (Geonomics, Inc. 1978).

Zinc is an essential micronutrient for normal plant growth. It is present in all plants in varying concentrations between 1 and 10 ppm. Cereal grains exhibit levels up to 140 ppm (McKee and Wolf 1963). Zinc is required in the production of precursors of the plant hormone, auxin. Auxin is a growth regulator; therefore, zinc deficiencies result in poor growth, morphological and physiological deformities, and chemical imbalance (Salisbury and Ross 1969).

Deficiencies are more frequent than toxicities. Concentrations in the range of 10.5 to 32.7 ppm in leaves are adequate for most plants; some (e.g., ragweed) accumulate over 4,000 ppm. Most plants accumulate zinc in leaves, but several (corn, for example) accumulate high concentrations at the nodes (Seatz and Jurinak 1957).

Zinc deficiencies reduce the amount of nitrogen in plant tissue and increase the potassium and phosphorus content to higher than normal levels (Antonovics et al. 1971).

Crops of barley, oats, and wheat irrigated with geothermal effluent in the Raft River experiment showed no statistical difference in zinc concentration of grains when compared with crops irrigated with "fresh" water. Oats averaged 13 ppm, wheat 11 ppm, and barley 26 ppm (Schmitt and Spencer 1977). Oats exhibit levels of up to 100 ppm zinc without showing signs of toxicity (McKee and Wolf 1963).

Studies utilizing such wetlands plant species as bulrush, sedge, cattail, and reed indicate relatively high zinc absorption ability. Tissue values of 50 mg/kg, 63 mg/kg, 47 mg/kg, and 37 mg/kg dry weight, respectively, indicate the high tolerance of these species to zinc (Seidel 1976). Water hyacinths can tolerate solution concentrations of greater than 10 ppm zinc without toxic effects.

Hydroponic studies using eight marsh species and four different salinity levels indicated that all species studied had the ability to take up and translocate zinc at a minimum concentration in the roots of 150 ppm. Saltwater plants absorb and translocate higher concentrations of zinc than do brackish or freshwater plants (Lee et al. 1976).

Aquatic vegetation appears generally tolerant of high levels of zinc; however, zinc can function as an algacide. Concentrations of 70 ppm have been found to be lethal to the alga Selenastrum. Toxicity of zinc is governed by the metabolic rate of the organism in a linear fashion (Bartlett and Rabe 1974).

Although zinc is readily accumulated in leaves and nodes of most plants, bioaccumulation in the food chain does not appear to occur, due to the formation of insoluble complexes with calcium in plant tissues. These complexes are then unavailable to animals.

The presence of copper, cadmium, or nickel has a synergistic effect on zinc, while calcium has an antagonistic effect. Toxicity of zinc salts is increased when the concentration of dissolved oxygen is decreased. The addition of lime to soils decreases toxic effects of zinc. The presence of excess phosphorus in soils also decreases zinc toxicity, by forming an insoluble zinc phosphate complex (Seatz and Jurinak 1957).

Fauna

Aquatic invertebrates tested for zinc toxicity include Daphnia, Acroneuria lycorias, Ephemerella subvaria, Hydropsyche betteri, and Physa heterostropha (Dvorak and Lewis 1978). One of the most sensitive of these is the snail Physa. Its soft water 96-hour LC_{50} was 0.3 ppm. Daphnia was even less tolerant, with a 48-hour LC_{50} of 0.1 ppm. Daphnia also experienced a 16% reproductive impairment after a 3-week exposure to 0.07 ppm Zn.

The sensitivity of warmwater fish species to zinc begins at approximately 0.88 ppm. At this concentration, the guppy (Poecilia reticulata) experienced a reduction in both brood size and size of its offspring. Fathead minnows had a 96-hour LC_{50} level of 0.96 ppm Zn.

U.S. Environmental Protection Agency (1976) has set the criterion at 0.01 times the 96-hour LC_{50} of the most sensitive species.

APPENDIX C. NATURAL HOT SPRING DATA

Table C-1. List of natural hot springs whose data were used in the compilation of Column 3, Table C-2.

State	Site	County
California	Calistoga Hot Springs	Napa
	Sonoma Hot Springs	Sonoma
	Amedee Hot Springs	Lassen
Idaho	Raft River	Cassia
	Crane Creek Hot Springs	Washington
	Weiser Hot Springs	Washington
	N.E. Boise Thermal Area	Ada
Montana	Gregson Hot Springs	Silverbow
	Norris Hot Springs	Madison
Nevada	Elko Hot Springs	Elko
	Beowawe	Eureka
	Gol Conda Hot Springs	Humboldt
	Wabuska	Lyon
	Mud Hot Springs	Washoe
New Mexico	Radium Hot Springs	Dona Ana
	Gilia Hot Springs	Grant
	Iron Springs	Toos
Oregon	Hunters Lodge	Lake
	Breitenbush Hot Springs	Marion
	Vale Hot Springs	Malheur
Utah	Crystal Hot Springs	Box Elder
	Utah Hot Springs	Weber
	Joseph Hot Springs	Sevier

Table C-2. Basis of establishment of criteria.

Parameter	Criteria establishment Level 1	Level 2
TDS	(1)	(2);(6)
pH	(2);(6)	
Ag	(4)	(3a)
AL	(4a)	(3b)
AS	(1)	(3b)
B	(5)	(3b)
Ba	(1)	(6)
Be	(5)	(3b);(6)
Br	(4a)	
Ca	(1)	(1)
Cd	(1);(5);(3a)	(3b)
Cl	(1);(5)	(3a)
Cr	(1);(3a)	(3b)
Cu	(1)	(3b)
F		(6)
Fe	(4)	(3b)
H_2S	(4)	
Hg	(4)	(3b)
I	(4a)	(4b)
K	(4)	
Li	(4a)	(4b)
Mg	(3a)	(3b)
Mn	(1);(3a)	(3b)
Mo	(1)	(3a)
NH_4	(4)	(6)
Na	(1)	(2);(3a)
Ni	(1)	(3b)
NO_3	(4a)	(4b)
Pb	(1);(3a)	(3b)
PO_4		(6)
Sb	(4a)	(4b)
Se	(1);(5)	(3b)
Sn	(4a)	(4b)
SO_4	(1);(31)	(3b)
V	(3a)	(3b)
Zn	(1);(3a)	(3b)

(1) State water quality (WQ) standards (domestic or livestock), discharge regulations.
(2) Existing refuge data.
(3) Natural hydrothermal spring data:
    (a) Average.
    (b) High values but vegetation still present.
(4) LD_{50} data for invertebrate species (nonspecific):
    (a) Safety factor of 0.1.
    (b) Order of magnitude greater than 4a.
(5) Recommended irrigation standards.
(6) Tolerance limits of desirable marsh plants.

APPENDIX D. QUESTIONNAIRE AND AGENCIES IT WAS SENT TO

QUESTIONNAIRE

UTILIZING GEOTHERMAL EFFLUENTS TO CREATE NEW WILDLIFE AND WATERFOWL HABITATS

1. Would you support the idea of utilizing geothermal effluents to create new wildlife and waterfowl habitat?

2. Would you hunt ducks or other game birds known to utilize geothermal effluent wetlands?

3. Do you have any reservations about eating ducks or other fowl that utilize such habitat?

4. Do you have any suggestions about potential uses for these new wetlands?

5. What do you consider the top priorities should be for using the wetlands?

6. Do you have any concerns about utilizing geothermal wetlands for hunting or other recreational uses?

7. Would you be willing to pay a fee to use these areas for hunting, recreation, or other uses?

8. We would like to know if you have any other comments about the potential use of geothermal wetlands for creating new wildlife habitat.

AGENCIES QUESTIONNAIRE WAS SENT TO

Nevada

Nevada Department of Wildlife
Nevada Department of Conservation and Natural Resources
Nevada Wildlife Federation
Wildlife Society, Nevada Chapter

Idaho

Idaho Department of Fish and Game
Idaho Cooperative Wildlife Research Unit (USDI)
Idaho Wildlife Federation
Idaho Environmental Council
Wildlife Resources
Wildlife Society, Idaho Chapter

Oregon

Oregon Department of Fish and Wildlife
Ducks Unlimited
Oregon Wildlife Federation
Oregon Environmental Council
Oregon Wilderness Coalition
Wildlife Society, Oregon Chapter
Sierra Club

Montana

Montana Department of Fish, Wildlife and Parks
Montana Department of Natural Resources and Conservation
Montana Cooperative Wildlife Research Unit
Montana Wildlife Federation
Northern Rockies Action Group, Inc.
Wildlife Society, Montana Chapter

Utah

Utah Department of Natural Resources
Utah Cooperative Wildlife Research Unit (USDI)
Utah Wildlife and Outdoor Recreation Federation
Defenders of the Outdoor Heritage
Utah Nature Study Society
Wildlife Society, Utah Chapter

New Mexico

New Mexico Department of Natural Resources
New Mexico Wildlife Federation
The Nature Conservancy
Wildlife Society, New Mexico Chapter

California

- California Resources Agency
  - Department of Conservation
  - Department of Water Resources
  - Wildlife Conservation Board
- California Natural Resources Federation
- California Trappers Association
- Mt. Shasta Area Audubon Society
- The Nature Conservancy

Total Organizations: 40

APPENDIX E. NAMES OF GEOTHERMAL AREAS.

Table E-1. Geothermal wetlands.

Site number in CH2M report (from chemical table)	County	Name in hydrothermal baseline study	Name in USGS resource assessment	Area name in CH2M report
Idaho sites				
5	Adams			Cascade Reservoir
6	Blaine	Gayer Hot Springs		Sun Valley/Ketchum
7	Blaine			Sun Valley/Ketchum
8	Boise	Boise Hot Springs		Grimes
9	Camas	Wardrop Hot Springs	Camas Prairie	Coral
10	Camas	Wardrop Hot Springs	Camas Prairie	Coral
15	Elmore			Glenns Ferry/Bliss
16	Gooding	White Arrow Hot Springs	S.W. Idaho	Glenns Ferry/Bliss
21	Custer	Loon Creek Hot Springs	Stanley-Challis	Sunbeam
Montana sites				
2	Jefferson	Alhambra (Sunnyside) Hot Springs		Helena
3	Jefferson	Boulder Hot Springs		Helena
16	Sanders	Camas Hot Springs	Little Bitteroot	Flathead Indian Reservation
17	Sanders	Quinn's Hot Springs		Flathead Indian Reservation
18	Beaverhead	Elkhorn (Polaris) Hot Springs		Dillon
19	Beaverhead	Jackson (Jardine) Hot Springs	Jackson	Dillon
Oregon sites				
14-21	Klamath	Klamath and Klamath Hills	Klamath Falls	Klamath Falls
15-18	Klamath	Klamath and Klamath Hills	Klamath Falls	Klamath Falls
Northern California sites				
3	Lassen			Honey Lake Valley
6	Modoc		Surprise Valley	Surprise Valley/ Modoc Plateau
13	Modoc		Surprise Valley	Surprise Valley/ Modoc Plateau
Nevada sites				
15-19	Nye	Darrough's Hot Springs	N. Big Smokey Valley	Darrough's
63-68	Washoe	Steamboat Hot Springs	Sierran Front	Steamboat Springs
79, 80	White Pine		Hot Creek Valley	Warm Springs

Table E-1. (concluded)

Site number in CH2M report (from chemical table)	County	Name in hydrothermal baseline study	Name in USGS resource assessment	Area name in CH2M report
New Mexico sites				
9	Grant	Gila Hot Springs (?)	The Meadows - Gila Hot Springs	Gila Wilderness
12	Sandoval			Los Alamos/Taos
15	Sandoval			Los Alamos/Taos
18	Socorro		Socorro	Socorro

APPENDIX F. PERSONAL COMMUNICATIONS

CALIFORNIA

Tyrus Berry, Refuge Manager, Havasu National Wildlife Refuge (WR)
Jim Bower, Biologist, California Wildlife Areas
Thomas Charmley, Refuge Manager, Kern/Pixley National WR
Ed Collins, U.S. Fish and Wildlife Service, Sacramento
Edward Crawford, Water Resources Control Board, State Region V (Central Valley)
Laurence Dean, Refuge Manager, Salton Sea National WR
Robert Fields, Refuge Manager, Klamath National WR
Geothermal Resources Council
Dick Hansen, State Pollution Lab, Sacramento
Joe Holmes, Biologist, Sacramento National WR
Lynn Howard, California Regional Team Leader, USFWS
Dr. John Koranda, Lawrence Livermore Labs, Livermore
Bob Ladon, Regional Director, California Wildlife Areas, Sacramento
Leon Littlefield, Refuge Manager, San Luis National WR
Joe Robinson, Union Oil, Los Angeles
Bob Weld, Honey Lake Waterfowl Area

IDAHO

Mel Branch, Refuge Manager, McArthur Lake State WR
Norris Burton, Refuge Manager, Haggerman State WR
Pete Carter, U.S. Fish and Wildlife Service, Boise
Deer Flat National Wildlife Refuge
Gerald Ducher, Refuge Manager, Grey Lake National WR
Eric Glover, Water Power Resources, Boise
John Hill, Refuge Manager, Minidoka National WR
Idaho Fish and Game, Jerome
Kootenai National Wildlife Refuge
Arch Mehroff, Regional Team Leader, USFWS
Jack Richardson, Refuge Manager, Camas National WR
Wally Roberts, Refuge Manager, Fort Boise State WR
Mike Smith, Idaho Water Quality Bureau, Boise

MONTANA

Micky Beland, Resource Coordinator, West Yellowstone, Known Geothermal Resource Area (KGRA)
Jay Bellinger, Refuge Manager, Medicine Lake National WR
Bob Blue, Area Manager, USFWS
R. Freas, Refuge Manager, C. M. Russel National WR
Gary Hagedorn, Refuge Manager, Northwest Wetland Management District
Jay Hammerick, U.S. Fish and Wildlife Service, Billings
John Lloyd, Biologist, USFWS
John Malcom, U.S. Fish and Wildlife Service, Billings
Montana Department of Fish and Game, Billings
Harvey Nyberg, Freezout Lake WR

MONTANA (continued)

Robert Pearson, Refuge Manager, Benton Lake National WR
Eugene Shoops, Refuge Manager, Red Rock Lakes National WR
Gene Sipe, Refuge Manager, Bowdoin National WR
Robert Twist, Refuge Manager, Lee Metcalf National WR

NEVADA

Larry Barngrover, Waterfowl Biologist, Nevada Fish and Game, Reno
Donald Gilmore, USEPA Environmental Monitoring and Support Lab, Las Vegas
Lynn Howard, Stillwater Wildlife Refuge, Nevada
Larry Kline, Ruby Lake Refuge, Elko
Wendel McCurry, State Division of Environmental Protection, Department of Conservation and Natural Resources
Phillips Petroleum, Desert Peak
Mr. Wolcot, U.S. Fish and Wildlife Service, Las Vegas

NEW MEXICO

John Brock, Refuge Manager, Maxwell National WR
Marshal Conway, New Mexico Department of Game and Fish, Santa Fe
Nita Fuller, Bosque del Apache WR
Pat Gessner, Public Affairs Division, Santa Fe
Maxine Good, State Environmental Protection Division, Water Quality Control Commission
James Johnson, Project Leader, Development--New Mexico State Game & Fish
Joe Kathrein, Regional Team Leader, USFWS
John Kiger, Refuge Manager, San Andres National WR
LeMoyne Marlatt, Refuge Manager, Bitter Lake National WR
Ronald Perry, Refuge Manager, Bosque del Apache National WR
Art Wilbur, Department of Energy, Santa Fe

OREGON

Jerry Bell, Department of Environmental Quality, Water Quality Lab, Portland
Mr. Bowman, Refuge Manager, Deman Game Refuge
A. Boyd Claggett, Refuge Manager, Summer Lake State Game Refuge
Bob Cleary, Regional Team Leader, USFWS
Environmental Protection Agency, Portland
Deborah Justis, Department of Energy, Salem
John Kurtz, Refuge Manager, Umatilla National WR
F. Lemay, Refuge Manager, D. E. Wilson Game Refuge
J. Mazzoni, Refuge Manager, Malheur National WR
Chris McKay, Refuge Manager, William L. Finley National WR
Refuge Manager, Modoc National WR
Ed Quan, State Department of Environmental Quality, Water Quality Section
Jean Ryan, Oregon Institute of Technology, Klamath Falls
Dr. Lloyda Thompson Crowley, Oregon State University, Corvallis

UTAH

Edwin Cornea, Refuge Manager, Desert Lake State WR
Environmental Protection Agency, Salt Lake City
Neil Folks, Refuge Manager, Browns Park State WR
Noland Neilson, Refuge Manager, Ogden Bay State WR
Ned Peabody, Refuge Manager, Bear River National WR
Earl Pierce, State Division of Public Health, Bureau of Water Pollution
Lewis Richardson, Regional Team Leader, USFWS
Dallas Taylor, Refuge Manager, Salt Creek State WR
Herbert L. Troester, Refuge Manager, Ouray National WR
U.S. Fish and Wildlife Service, Salt Lake City
Ward Waystaff, Utah Division of Water Rights, Salt Lake City
Larry J. Wilson, Supervisor, Southeastern Region, Utah Division of Wildlife Resources

MISCELLANEOUS

Hal Boeker, Regional Team Leader, USFWS, Denver, Colorado
William Jordan, USEPA Effluent Guideline Division Office, Washington, D.C.
Patuxent Wildlife Research Center, Maryland
Prairie Wildlife Research Center, Bismarck, North Dakota

APPENDIX G

Anderson, B. G. 1948. The apparent thresholds of toxicity to *Daphnia magna* for chlorids of various metals when added to Lake Erie water. Trans. Am. Fish. Soc. 78:96-113.

Antonovics, J., A. D. Bradshaw, and R. G. Turner. 1971. Heavy metals tolerance in plants. Pages 2-85 *in* J. B. Cragg, ed. Advances in ecological reserach; Vol. 7. Academic Press, N.Y. 257 pp.

Arthur, J. W., and E. N. Leonard. 1970. Effects of copper on *Gammarus pseudolimnaeus*, *Physa integra*, and *Campeloma decisum* in soft water. J. Fish. Res. Bd. Canada 27:1277-1283.

Atherton, R. W., E. J. Finnemore, and M. L. Gilliam. 1976. The analysis of subsidence associated with geothermal development, vol. 2. Research Report, Systems Control, Inc.

Barnes, A. B. 1980. Pitt Marsh: Bio-improvement proposal. Ducks Unlimited (Canada), Vancouver, B.C. 15 pp.

Bartlett, L., and F. R. Rabe. 1974. Effects of copper, zinc, and cadmium on *Selanastrum capricornutum*. Water Res. 8:179-185.

Bear, F. E. 1957. Toxic elements in soils. Pages 165-171 *in* A. Stefferud, ed. Soil; The 1957 Yearbook of Agriculture. U.S. Dept. Ag., Govt. Printing Office, Wash., D.C. 784 pp.

Becker, C. D., and T. O. Thatcher. 1973. Toxicity of power plant chemicals to aquatic life. Prepared for U.S. Atomic Energy Commission. Battelle Pacific Northwest Labs, Richland, Wash. WASH-1249.

Bellrose, F. 1978. Advances in waterfowl management reserach. Wildl. Soc. Bull. 6(2):63-72.

Benoit, D. A. 1975. Chronic effects of copper on survival, growth, and reproduction of the bluegill *Lepomis macrochirus*. Trans. Am. Fish. Soc. 104:353-360.

Benson, W., D. Brock, J. Gabica, and M. Loomis. 1976. Swan mortality due to certain heavy metals in Mission Lake area, Idaho. Bull. Environ. Contamin. Toxicol. 15:171-174.

Bond, J. G., 1978. Geologic Map of Idaho. Idaho Dept. of Lands, Bur. of Mines & Geology, Scale: 1:500,000.

Boyd, C. E. 1978. Chemical composition of wetland plants. Pages 155-194 *in* R. E. Good, D. F. Whigham, R. L. Simpson, and C. G. Jackson, Jr., eds. Freshwater Wetlands: Ecological processes and management potential, Academic Press, N.Y.

Boyd, C. E. 1979. Water quality in warmwater fish ponds. Auburn Univ., Agricultural Experiment Station, Auburn, Alabama. 359 pp.

Brisbin, I. 1974. Abundance and diversity of waterfowl inhabiting heated and unheated portions of a reactor cooling reservoir. Pages 578-593 in J. W. Gibbons and R. R. Schartz, eds. Thermal Ecology proceedings of a symposium; AEC symposium series; 1973 May 3-5, Augusta, GA. (Savannah River Ecology Lab, Aiken, S.C.) 867 pp. Available from NTIS, Springfield, VA, CONF-730505-5.

Broadbent, F. E. 1957. Organic matter. Pages 151-156 in A. Stefferud, ed. Soil; The 1957 Yearbook of Agriculture, U.S. Dept. of Ag., Govt. Printing Office, Wash., D.C. 784 pp.

CH2M HILL. 1979. Draft wastewater management environmental assessment. Incline Village General Improvement District. Redding, CA.

Clark, W. O., and Riddell, C. W. 1920. Exploratory drilling for water and use of ground water for irrigation in Steptoe Valley, Nevada. USGS Water-Supply Paper 467. 70 pp.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1977. Classification of wetlands and deep-water habitats of the United States (an operational draft). U.S. Dept. of Int., Fish and Wildl. Serv. 100 pp.

Cox, J. A., J. Carnahan, J. Di Nunzio, J. McCoy, and J. Meister. 1979. Source of mercury in fish in new impoundments. Bull. Environ. Contam. Toxicol. 23(6):779-783.

Crow, N., n.d. Outline of tutorial on induced subsidence and seismicity in geothermal areas. Geothermal Resources Council Management Survey Course No. 3. Davis, California.

Cunningham, L. M. 1975. Cadmium toxicity and autoradiography in soybean in symposium proceedings of the International Conference on heavy metals in the environment; Vol. 2, pt. 1.

Czerwenka, W., and K. Seidel. 1976. The combination of biological and chemical treatment at the Krefeld water treatment works. Pages 287-294 in J. Tourbier and R. W. Pierson, Jr., eds. Biological control of water pollution. Univ. of Penn. Press, Philadelphia, Pennsylvania.

deHaan, F. A. M. 1977. The effects of long-term accumulation of heavy metals and selected compounds in municipal wastewater on soil. Pages 283-319 in F. M. D'Itri, ed. Wastewater renovation and reuse. Marcel Dekker, Inc., N.Y.

deJong, J. 1976. The purification of wastewater with the aid of rush or reed ponds. Pages 133-140 in J. Tourbier and R. W. Pierson, Jr., eds. Biological control of water pollution. Univ. of Penn. Press, Philadelphia, Pennsylvania.

de la Cruz, A. A. 1978. Primary production process: Summary and recommendations. Pages 79-86 in R. E. Good, D. F. Whigham, R. L. Simpson, and C. G. Jackson, Jr., eds. Freshwater Wetlands: Ecological processes and management potential. Academic Press, N.Y.

Demgen, C., and J. Warren Nute. 1979. Wetlands aeration using secondary treated wetlands. Pages 727-739 in proceedings, water reuse symposium, vol. 1, March 25-30, 1979, Washington, D.C.

Dieter, M., and M. Finley. 1979. Aminolevulinic acid dehydratase enzyme activity in blood, brain, and liver of lead-dosed ducks. Environ. Res. 19:127-135.

D'Itri, F. M., ed. 1977. Wastewater renovation and reuse. Marcel Dekker, Inc. N.Y. 705 pp.

Driver, E.A., L. G. Sugden, and R. J. Kovach. 1974. Calorific, chemical and physcial values of potential duck food. Fresh Water Biol. 4:281-292.

Duffer, W. R., and J. E. Moyer. 1978. Municipal wastewater aquaculture. U.S. Robert S. Kerr Environmental Reserach Lab, Ada, OK. NTIS No. PB-284-352. 46 pp.

Dustman, E., L. Stickel, and J. Elder. 1972. Mercury in wildl animals, Lake St. Clair, 1970. Pages 46-52 in R. Hartung and Dinmain, eds. Environmental Mercury Contamination. Ann Arbor Science Publ., Ann Arbor, MI.

Dvorak, A. J., and B. G. Lewis. 1978. Impacts of coal-fired power plants on fish, wildlife, and their habitats. U.S. Fish and Wildlife Service, Office of Biological Services and Environmental Contaminants Evaluation. FWS/OBS-78/29. 260 pp.

EG&G, Inc., and Idaho National Engineering Laboratory. 1978. Semiannual progress report for the Idaho geothermal program, April 1 to September 30, 1978. Prepared for U.S. Department of Energy under contract No. EY-76-C-07-1570. 87 pp.

Ernst, W. H. O. 1975. Physiology of heavy metals resistance in plants. In symposium proceedings of the International Conference on heavy metals in the environment; Vol. 2; pt. 1.

Ewel, K. C. 1976. Effects of sewage effluent on ecosystem dynamics in cypress domes. Pages 169-196 in D. L. Tilton, R. H. Kadlec, and C. J. Richardson, eds. Freshwater wetlands and sewage effluent disposal; proceedings of a symposium; May 10-11, 1976, Ann Arbor, Michigan.

Finley, M., and R. Stendell. 1978. Survival and reproductive success of Black Ducks fed methylmercury. Environ. Pollut. 16:51-64.

Finley, M., W. Stickel, and R. Christensen. 1979. Mercury residues in tissues of dead and surviving birds fed methylmercury. Bull. Environ. Contamin. Toxicol. 21:105-110.

Fluor Engineers and Constructors, Inc. 1978. Desalting plans and progress, an evaluation of the state-of-the-art and future research and development requirements. Executive summary report for U.S. Dept. of the Interior. 41 pp.

Freeze, R. A., and Cherry, J. A. 1979. Groundwater. Prentice-Hall, Englewood, N.J. 604 pp.

Geonomics, Inc. 1978. Geothermal Environmental Impact Assessment; Subsurface environmental assessment for four geothermal systems. Prepared for U.S. Environmental Protection Agency, Environ. Monit. and Supp. Lab., Las Vegas, NV. EPA-600/7-78-207. 240 pp.

Geothermal Task Force. 1980. Final report to the Oregon Alternative Energy Development Commission. Salem, Oregon. 55 pp.

Grimsrud, G. P., B. L. Turner, and P. A. Frame. 1978. Areas of ground subsidence due to geofluid withdrawal. Geothermal Subsidence Research Management Program, Earth Sciences Division, Lawrence Berkeley Labs, U.C. Berkeley, prepared for DOE Contract W-7405-ENG-48. 70 pp.

Hartley, R. P. 1978. Pollution Control Guidance for Geothermal energy development. Industrial Environmental Research Laboratory, Office of Research and Development. U.S. Environmental Protection Agency, EPA-600/7-78-101, 133 pp.

Heinz, G. 1974. Effects of low dietary levels of methylmercury on mallard reproduction. Bull. Environ. Contamin. Toxicol. 11(4):386-392.

Heinz, G. 1975. Effects of methylmercury on approach and avoidance behavior of mallard ducklings. Bull. Environ. Contamin. Toxicol. 13(5):554-564.

Heinz, G. 1976a. Methylmercury: second year feeding effects on mallard reproduction and duckling behavior. J. Wildl. Manage. 40(1):82-90.

Heinz, G. 1976b. Methylmercury: second generation reproductive and behavioral effects on mallard ducks. J. Wildl. Manage. 40(4):710-715.

Heinz, G. 1979. Methylmercury: Reproductive and behavioral effects on three generations of mallard ducks. J. Wildl. Manage. 43(2):394-401.

Heinz, G., and L. Locke. 1976. Brain lesions in mallard ducklings from parents fed methylmercury. Avion Diseases 20(1):9-17.

Hill, E., and C. Shaffner. 1976. Sexual maturation and productivity of Japanese quail fed graded concentrations of mercuric chloride. Poultry Science 55:1449-1459.

Hill, E., and J. Soares. 1977. Reproductivity of Japanese quail fed mercuric chloride in the absence of Vitamin D. Poultry Science 56:710-712.

Hunt, C. H. 1978. Surficial geology of New Mexico. New Mexico Bureau of Mines and Mineral Resources Geologic Map 43, 1:500,000.

Hunter, B., W. Clark, P. Perkins, and P. Coleman. 1970. Applied botulism research including management recommendations. Calif. Dept. Fish and Game, Wildl. Manage. Prog. Rept. 87 pp.

Hutchison, F., and C. M. Wai. 1979. Cadmium, lead, and zinc in reclaimed phosphate mine dumps in Idaho. Bull. Environ. Contam. Toxicol. 23(3):377-380.

Hynes, H. B. N. 1970. The ecology of running waters. The Liverpool Univ. Press, Liverpool, England. 555 pp.

Irwin, J., and L. Karstad. 1972. The toxicity for ducks of disintegrated lead shot in a simulated marsh environment. J. of Wildlife Diseases 8:149-153.

Jacobson, J. S., and A. C. Hill, eds. 1970. Recognition of air pollution injury to vegetation: a pictorial atlas. Air Pollution Control Association, Pitts., Penn. 39 pp.

Jensen, F. 1974. Evaluation of existing wetland habitat in Utah. Utah Division of Wildlife Resources, Pub. 74-17. 192 pp.

de Jong, J. 1976. The purification of wastewater with the aid of rush or reed ponds. Pages 133-139 *in* J. Tourbier and R. W. Pierson, Jr., eds. Biological Control of Water Pollution. Univ. of Penn. Press, Philadelphia, Pennsylvania. 335 pp.

Kadlec, R. H., D. L. Tilton, and J. A. Kadlec. 1977. Feasibility of utilization of wetland ecosystems for nutrient removal from secondary municipal wastewater treatment plant effluent. Semi-Annual Report No. 5, Univ. of Michigan, Ann Arbor, MI. For National Sci. Found. Grant AEN75-08855. 364 pp.

Keeney, D. R., and L. M. Walsh. 1975. Heavy metals in sludge-amended soils *in* symposium proceedings of the International Conference on heavy metals in the environment. Vol. 2, pt. 1.

Kenaga, E. E., and R. J. Moolenaar. 1979. Fish and *Daphnia* toxicity as surrogates for aquatic vascular plants and algae. Environ. Sci. & Tech. 13(12):1479-1480.

Koranda, J., K. Moore, M. Stuart, and C. Conrado. 1979. Dietary effects on lead uptake and trace element distributions in mallard ducks dosed with lead shot. Lawrence Livermore Laboratory, CA. UCID-18044.

Lee, C. R., T. C. Sturgis, and M. C. Landin. 1976. A hydroponic study of heavy metal uptake by selected marsh plant species: Final Report. U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss. Tech. Rept. D-76-5. 47 pp.

LeGrande, H. E. 1980. A standardized system for evaluating waste-disposal sites. National Water Well Association 42 pp.

Levin, G. V. 1960. Sodium chlorid uptake by algae. Public Work 91:7-95.

Lindsley, D., T. Schuck, and F. Stearns. 1976. Productivity and nutrient content of emergent macrophytes in two Wisconsin marshes. Pages 51-77 in D. L. Tilton, R. H. Kadlec, and C. J. Richardson, eds. Freshwater wetlands and sewage effluent disposal; proceedings of a symposium; May 10-11, 1976, Ann Arbor, Michigan.

McKee, J. E., and H. W. Wolf, eds. 1963. Water quality criteria, 2nd edition. State Water Quality Control Board, Publ. No. 3-A. Sacramento, CA 548 pp.

McNabb, C. D. 1976. Potential of submersed vascular plants for reclamation of wastewater in temperate zone ponds. Pages 123-132 in J. Tourbier and R. W. Pierson, Jr., eds. Biological control of water pollution. Univ. of Penn. Press, Phil., PA. 335 pp.

McNeil, W. J. 1978. Overview:. Geothermal resources and aquaculture. Geothermal Resources for Aquaculture; Proceeding of a Workshop, Boise, Idaho. Oregon State Univ., Sea Grant College Program, Pub. no. ORESU-W-78-001.

Miller, P. C. 1974. Potential use of vegetation to enhance cooling in holding ponds in J. W. Gibbons and R. R. Shartiz, eds. Thermal Ecology: proceedings of a symposium; AEC symposium series; 1973 May 3-5, Augusta, GA. (Savannah River Ecology Lab, Aiken, S.C.) 687 pp. Available from: NTIS, Springfield, VA; CONF-730505-5.

Miller, S. 1977. The impact of thermal effluents on fish. Env. Biol. Fish. 1(2):219-222.

Muffler, L. J. P. (ed.). 1979. Assessment of geothermal resources of the United States - 1978. Geological Survey Circular 790 (+map). 163 pp.

Odum, E. P. 1971. Fundamentals of Ecology, 3rd ed. Saunders, Phil., PA. 574 pp.

Olsen, S. R., and M. Fried. 1957. Soil phosphorus and fertility. Pages 94-100 in A. Stefferud, ed. Soil; The 1957 Yearbook of Agriculture. U.S. Dept. Ag.; Govt. Printing Office, Wash., D.C. 784 pp.

Oseid, D. M., and L. L. Smith, Jr. 1974. Factors influencing acute toxicity estimates of hydrogen sulfide to freshwater invertebrates. Water Res. 8:739-46.

Patrick, R. 1974. Effects of abnormal temperature on algae communities in J. W. Gibbons and R. R. Shartiz, eds. Thermal Ecology: proceedings of a symposium; AEC symposium series; 1973, May 3-5, Augusta, GA. (Savannah River Ecology Lab, Aiken, S.C.) 867 pp. Available from: NTIS, Springfield, VA; CONF-730505-5.

Poland, J. F. 1976. Land subsidence in western United States in: Focus on environmental geology. Oxford Univ. Press, New York, New York.

Poland, J. F., and G. H. Davis. 1969. Land subsidence due to withdrawal of fluids in Reviews in Engineering Geology, vol. II, Geol. Soc. of America, Boulder, Colorado.

Rehwoldt, R., L. Lasko, C. Shaw, and E. Wirhowski. 1973. The acute toxicity of some heavy metal ions toward benthic organisms. Bull. Environ. Contam. Toxicol. 10(5):291-294.

Reitemeier, R. F. 1957. Soil potassium and fertility. Pages 101-106 in A. Stefferud, ed. Soil; the 1957 Yearbook fo Agriculture. U.S. Dept. of Ag., Govt. Printing Office, Wash., D.C. 784 pp.

Reuther, W. 1957. Copper and soil fertility. Pages 128-134 in A. Stefferud, ed. Soil; The 1957 Yearbook of Agriculture. U.S. Dept. of Ag., Govt. Printing Office, Wash., D.C. 784 pp.

Richardson, C. J., W. A. Wentz, J. P. M. Chamie, J. A. Kadlec, and D. L. Tilton. 1976. Plant growth, nutrient accumulation, and decomposition in a central Michigan peatland used for effluent treatment. Pages 77-118 in D. L. Tilton, R. H. Kadlec, and C. J. Richardson, eds. Freshwater wetlands and sewage effluent disposal; proceedings of a symposium; May 10-11, 1976, Ann Arbor, Michigan.

Richardson, C. J. 1978. Nutrient dynamics of northern wetlands. Pages 217-241 in R. E. Good, D. F. Whigham, R. L. Simpson, and C. G. Jackson, Jr., eds. Freshwater Wetlands: Ecological processes and management potential, Academic Press, N.Y.

Rodgers, J. H., Jr., D. S. Cherry, and R. K. Guthrie. 1978. Cycling of elements in duckweed (Lemna perpusilla)in an ash settling basin and swamp drainage system. Water Res. 12:765-770.

Ross, C. P., D. A. Andrews, and I. J. Witkind. 1955. Geologic Map of Montana. Montana Bureau of Mines and Geology. Scale:1:500,000.

Ross, C. P., J. D. Forrester. 1977. Geologic Map of the State of Idaho. U.S. Geological Survey and __________. Bureau of Mines and Geology.

Saks, N. M., J. J. Lee, W. A. Muller, and J. H. Tietjen. 1974. Growth of salt-marsh microcosms subjected to thermal stress. Pages 391-398 in J. W. Gibbons and R. R. Shartiz, eds. Thermal Ecology: proceedings of a symposium; AEC Symposium series; 1973 May 3-5; Augusta, GA. (Savannah River Ecology Lab, Aiken, SC) 687 pp. Available from: NTIS, Springfield, VA.; CONF-730505-5.

Salisbury, F. B., and C. Ross. 1969. Plant physiology. Wadsworth Pub. Co., Inc., Belmont, CA. 747 pp.

Sammel, E. A. 1980. Hydrogeologic appraisal of the Klamath Falls geothermal area, Oregon. Geohydrology of geothermal systems, Geological Survey professional paper 1044-G. 43 pp.

Schmitt, R. C., and S. G. Spencer. 1977. Beneficial uses of geothermal energy; description and preliminary results for Phase 1 of the Raft River irrigation experiment. EG&G Idaho, Inc., Idaho Nat'l. Eng. Lab., Idaho Falls, ID. 42 pp.

Seatz, L. F., and J. J. Jurinak. 1957. Zinc and soil fertility. Pages 115-120 in A. Stefferud, ed. Soil; The 1957 Yearbook of Agriculture. U.S. Dept. of Ag., Govt. Printing Office, Wash., D.C. 784 pp.

Seidel, K. 1976. Macrophytes and water purification. Pages 109-122 in J. Tourbier and R. W. Pierson, Jr., eds. Biological control of water pollution. Univ. of Penn. Press, Phil., PA. 335 pp.

Sherman, G. D. 1957. Manganese and soil fertility. Pages 135-138 in A. Stefferud, ed. Soil; The 1957 Yearbook of Agriculture. U.S. Dept. of Ag., Govt. Printing Office, Wash., D.C. 784 pp.

Sloan, C. E. 1970. Biotic and hydrologic variables in prairie potholes in North Dakota. J. Range. Mang. 23(4):260-263.

Small, M. M. 1976. Marsh/pond sewage treatment plants. Presented at Freshwater Wetlands and Sewage Effluent Disposal Conference; 1976 May 10-11; Univ. of Mich., Ann Arbor, Mich. Available from: NTIS, Springfield, VA.; CONF-760526. 15 pp.

Snyder, C. T. 1963. Hydrology of stock-water development in the Ely Grazing District, Nevada. U. S. Geological Survey Water-Supply Paper 1475-L, pp. 383-441.

Spangler, F., W. SLoey, and C. W. Fetter. 1976a. Experimental use of emergent vegetation for the biological treatment of municipal wastewater in Wisconsin. Pages 161-172 in J. Tourbier and R. W. Pierson, Jr., eds. Biological control of water pollution. Univ. of Penn. Press. Phil., PA.

Spangler, F. L., W. E. Sloey, and C. W. Fetter, Jr. 1976b. Artificial and natural marshes as wastewater treatment systems in Wisconsin. Pages 215-240 in D. L. Tilton, R. H. Kadlec, and C. J. Richardson, eds. Freshwater wetlands and sewage effluent disposal; proceedings of a symposium; May 10-11, 1976, Ann Arbor, Michigan.

Stanley, N. E. 1979. Raft River Irrigation Experiment, Phase 2 Report. EG&G Idaho, Inc., Idaho Nat. Eng. Lab. 24 pp.

Stefferud, A. 1957. Soil; The 1957 Yearbook of Agriculture. U.S. Dept. Ag., Govt. Printing Office, Wash., D.C. 784 pp.

Stendall, R., H. Ohlendorf, E. Klass, and J. Elder. 1976. Mercury in eggs of aquatic birds, Lake St. Clair - 1973. Pesticides Monitoring Journal 10(1):7-9.

Stewart, J. H., and J. E. Carlson. 1977. Million-scale geologic map of Nevada. Nevada Bureau of Mines and Geology. Scale 1:1,000,000.

Stickel, L., W. Stickel, M. McLane, and M. Bruns. 1977. Prolonged retention of methylmercury by mallard ducks. Bull. Environ. Contam. Toxicol. 18(4):393-400.

Stout, P. R., and C. M. Johnson. 1957. Trace elements. Pages 139-150 in A. Stefferud, ed. Soil; The 1957 Yearbook of Agriculture. U.S. Dept. Ag., Govt. Printing Office, Wash., D.C. 784 pp.

Suter, G. W., II. 1978. Effects of geothermal energy development on fish and wildlife. U.S. Fish and Wildlife Service, Topical Brief: Fish and Wildlife Res. and Electric Power Generation, No. 6. FWS/OBS-76/20.6. 20 pp.

Sutherland, J. C. 1977. Investigation of the feasibility of tertiary treatment of municipal wastewater stabilization pond effluent using river wetlands in Michigan. William & Works, Grand Rapids, Mich. NSF ENV 76-20812. Available from: NTIS, Springfield, VA.; PB 275283.

Thomann, R. V., D. S. Szumski, D. M. Ditoro, and D. J. O'Connor. 1974. A food chain model of cadmium in Western Lake Erie. Water Res. 8:841-849.

Thomas, A. 1915. Effects of certain metal salts upon fishes. Trans. Am. Fish. Soc. 44:120-124.

Tourbier, J., and R. W. Pierson, Jr. eds. 1976. Biological control of water pollution. Univ. of Penn. Press Phil., PA. 335 pp.

Turner, R. E., J. W. Day, Jr., M. Meo, P. M. Payonk, T. B. Ford, and W. G. Smith. 1976. Aspects of land-treated waste application in Louisiana wetlands. Pages 145-168 in D. L. Tilton, R. H. Kadlec, and C. J. Richardson, eds. Freshwater wetlands and sewage effluent disposal; proceedings of a symposim; May 10-11, 1976, Ann Arbor, Michigan.

U.S. Environmental Protection Agency. 1974. Water Quality Criteria, 1972. National Academy of Sciences, National Academy of Engineering, U.S. Government Printing Office, Washington, D.C.

U.S. Environmental Protection Agency. 1976. Quality criteria for water. Pre-publication copy. Washington, D.C. 501 pp.

U.S. Environmental Protection Agency. 1977. Western energy resources and the environment:Geothermal Energy. EPA-600/9-77-010. 103 pp.

U.S. Soil Conservation Service. 1980. Guide for using soil survey single phase interpretation sheets. Portland, OR. 26 pp.

Valiela, I., and J. M. Teal, 1974. Nutrient limitation in salt marsh vegetation. Pages 547-583 in R. J. Reimold and W. E. Queen, eds. Ecology of halophytes.

Vernberg, F. J., and W. B. Vernberg. 1974. Synergistic effects of temperature and other environmental parameters on organisms. Pages 94-99 in J. W. Gibbons and R. R. Shartiz, eds. Thermal Ecology; proceedings of a symposium; AEC symposium series; 1973 May 3-5; Augusta, Georgia. (Savannah River Ecology Lab., Aiken, SC) 687 pp. Available from: NTIS, Springfield, VA; CONF-730550-5.

Viets, F. G., Jr., and J. J. Hanway. 1957. How to determine nutrient needs. pages 172-183 in A. Stefferud, ed. Soil: The 1957 Yearbook of Agriculture. U.S. Dept. Ag., Govt. Printing Office, Wash., D.C. 784 pp.

Waggett, A. 1969. An investigation of the potential problem of increasing boron concentrations in rivers and water courses. Water Res. 3:749-765.

Walker, E. H., and Sisco, H. G. 1964. Ground water in the Midvale and Council Areas, upper Weiser River basin, Idaho. U.S. Geological Survey Water-Supply Paper 1779-Q, pp. Q1-Q-26.

Wallen, I. E., W. C. Greer, and R. Lasater. 1957. Toxicity to Gambusia affinis of certain pure chemicals in turbid waters. J. of Sewage Industrial Wastes 29(6):695-711.

Walton, W. C. 1962. Ground-water resources of Camas Prairie, Camas and Elmore Counties, Idaho. U.S. Geological Survey Water-Supply Paper 1609, 57 pp.

Weiss, R. B., T. O. Coffey, and T. L. Williams. 1979. Geothermal Environmental Impact assessment. Harding-Lawson Assoc., U.S. Environmental Protection Agency, No. EPA-600. 17-79-218.

Weller, M. W. 1978. Management of Marshes for Wildlife. Pages 267-279 in R. E. Good, D. F. Whigham, R. L. Simpson, and C. G. Jackson, Jr., eds. Freshwater Wetlands: Ecological processes and management potential, Academic Press, N.Y.

Wells, F. G., and Peck, D. L. 1961. Geologic map of Oregon west of the 121st meridian. Oregon Dept. of Geol. and Mineral Industries. 1:500,000.

Whigham, D. F., and R. L. Simpson. 1976. The potential use of freshwater tidal marshes in the management of water quality in the Delaware River. Pages 173-186 in J. Tourbier and R. W. Pierson, Jr., eds. Biological control of water pollution. Univ. of Penn. Press, Philadelphia, Pennsylvania.

White, D., and M. Dieter. 1978. Effects of dietary vandium in mallard ducks. J. of Toxicology and Environmental Health 4:43-50.

White, D., and M. Finley. 1978a. Uptake and retention of dietary cadmium in mallard ducks. Environmental Reserach 17:53-79.

White, D., and M. Finley. 1978b. Effects of dietary cadmium in mallard ducks. Pages 220-223 in D. Hemphill, ed. Trace substances in environmental health. A symposium.

White, D., M. Finley, and J. Farrell. 1978. Histopathologic effects of dietary cadmium on kidneys and testes of mallard ducks. J. of Toxicology and Environmental Health 4:551-558.

Whitlow, T. H., and R. W. Harris. 1979. Flood tolerance in plants: A state-of-the-art report. Environmental and water quality operational studies. Tech. Rept. E-79-2. U.S. Army Engineers Waterways Experiment Station, Vicksburg, Miss. 16 pp.

Whittaker, R. H. 1975. Communities and ecosystems, 2nd ed. MacMillan Pub. Co., Inc., N.Y. 385 pp.

Williams & Works. 1977. Investigation of the feasibility of tertiary treatment of municipal wastewater stabilization pond effluent using river wetlands in Michigan. Grand Rapids, Mich. NSF ENV 76-20812. Available from: NTIS, Springfield, VA.; PB 275 283.

Windom, H. L. 1976. Geochemical interactions of heavy metals in southeastern salt marsh environments. Skidaway Inst. of Oceanography; Ecological Research Series. Available from: NTIS: PB-252-250. 35 pp.

Wolverton, B. C., R. M. Barlow, and R. C. McDonald. 1976. Application of vascular aquatic plants for pollution removal, energy, and food production in a biological system. Pages 141-150 in J. Tourbier and R. W. Pierson, Jr., eds. Biological control of water pollution. Univ. of Penn. Press, Phil., PA. 335 pp.

Woods, A. E., R. F. Carlton, M. E. Castro, and G. I. Gleason. 1979. Environmental bromine in freshwater and freshwater organisms: Factors affecting bioaccumulation. Bull. Environ. Contam. Toxicol. 23(1/2):179-185.

Young, D. 1974. Studies of Florida Gulf Coast salt marshes receiving thermal discharges. Pages 532-550 in J. W. Gibbons and R. R. Shartiz, eds. Thermal Ecology: proceedings of a symposium; AEC symposium series 1973 May 3-5, Augusta, GA. (Savannah River Ecology Lab., Aiken, SC) 687 pp. Available from: NTIS, Springfield, VA; CONF-730505-5.

APPENDIX H. SOIL AND GEOLOGIC INFORMATION

Table H-1. Soil information sources.

State	Site no.	Information source
CA[a]	13	Area unmapped
ID[b]	5	U.S. Soil Conservation Service (SCS) field office Most of area unmapped (Forest Service)
	6,7	SCS 1974 Part of area has not been mapped
	8	SCS 1976
	9,10	SCS field office
	21	Area unmapped (Forest Service)
MT[c]	16	SCS field office
	17	Area unmapped (Forest Service)
	18	Area unmapped (Forest Service)
	19	SCS field office
NV[d]	15-19	SCS 1980
	63-68	SCS field office
	79-80	Area unmapped
NM[e]	18	SCS field office Part of area unmapped
OR[f]	14-21	Oregon State Water Resources Board 1969

[a] CA = California

[b] ID = Idaho

[c] MT = Montana

[d] NV = Nevada

[e] NM = New Mexico

[f] OR = Oregon

Table H-2. Soil data (U.S. Conservation Service 1980).

			Estimated soil properties						Limitations and suitability ratings					
			Clay[a]											
State/ site no.	Soil series name	Interpretation sheet present	Depth (in)	%	Permeability (in/hr)[b]	High water table depth (ft)[c]	Cemented pan depth (in)[d]	Bedrock depth (in)[e]	Sewage lagoon	Sanitary landfill (area-type)	Pond reservoir area	Grassed waterways	Wetlands plants	Habitat-wildlife
	Orr	Yes	12-30	20-25	0.2-0.6	<6.0	-	<60	Severe--seepage	Severe--seepage	Severe--seepage	Slight	-	-
NV 63, 64,66-68	Vamp	See NV 65												
	Indian Creek	See NV 65												
	Spasprey	Yes	2-12	30-35	0.2-0.6	>6.0	20-30	>60	Severe, seepage, pan	Severe, pan	Moderate, seepage, pan	- cemented pan		
	Kayo	No	0-60	0-20	2.0-6.0	-	-	>60						
	Cassiro	Yes	15-45	35-50	0.2-0.6	>6.0	-	40-60	Moderate, slope, stones	Slight	- Slope	-	Poor	Very poor
NM 18	Pinaleno	No	2-30	20-35	0.2-0.6	-	-	>56						
	Nolam	Yes	2-17	20-35	0.6-2.0	>6.0	-	>60	Severe--seepage	Slight	Severe--seepage	-	Very poor	Very poor
	Chamberino	Yes	0-29	10-25	.06-0.2	>6.0	0	>60	Severe--seepage	-	Severe--seepage	- Stones	Very poor	Very poor
NM[p] 18	Apache	Yes	0-16	25-35	0.6-2.0	>6.0	-	4-20	Severe--depth to rock	Severe--depth to rock	Severe--depth to rock	- Depth to rock	Very poor	Very poor
	Nickel	Yes	7-19	5-10	0.2-0.6	>6.0	0	>60	Severe--seepage	Slight	Severe--seepage	- Stones	Very poor	Very poor
OR[q] 14, 17,19	Stukel	Yes	0-17	10-18	0.6-2.0	>6.0	-	10-20	Severe--depth to rock	Slight	- Depth to rock	- Rooting depth	Very poor	Very poor
OR 16,21	Stukel	See OR 14												
	Henley	Yes	11-20	18-25	0.6-2.0	1-3.5	20-40	>60	Severe--pan, wetness ness	Severe--seepage, wetness	- Pan, seepage	- Excess sodium, wetness	Poor	Poor
	Mosley	Yes	12-26	27-35	0.2-0.6	1-3.5	20-40	>60	Severe--pan, wetness	Severe--wetness	- Cemented pan	- Excess sodium, wetness, rooting depth	Poor	Poor

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Table H-2. (continued)

			Estimated soil properties						Limitations and suitability ratings					
			Clay[a]											
State/ site no.	Soil series name	Interpretation sheet present	Depth (in)	%	Permeability (in/hr)[b]	High water table depth (ft)[c]	Cemented pan depth (in)[d]	Bedrock depth (in)[e]	Sewage lagoon	Sanitary landfill (area-type)	Pond reservoir area	Grassed waterways	Wetlands plants	Habitat-wildlife
	Simonton	No	10-37	18-32	0.2-0.6	-	-	>60						
MT[j] 16	Allentine	No	3-60	40-60	<0.2	-	-	>60						
	Round Butte	Yes	7-14	35-60	<0.06	>6.0	-	>60	Slight	-	Slight	Erodible, hard to vegetate	-	-
MT 19	Slocum	No	10-40	20-35	0.6-2.0	40	-	>40						
	Bridger	Yes	9-24	35-50	0.6-2.0	>6.0	-	>60	Moderate--[k] seepage, slope	Slight[l]	- Slope, seepage	- Slope, percs slowly	Good	Fair[m]
NV[n] 15,16	Wrango	No	0-10	0-20	>20	-	-	>60						
	Oravada	Yes	0-61	5-18	0.6-2.0	>6.0	-	>60	Moderate-- seepage	Slight	Moderate-- seepage	- Erodes easily	Poor[o]	Poor
NV 17-19	Oravaba	See NV 15												
	Lahontan	Yes	0-63	35-60	<.06-0.2	>6.0	-	>60	Severe-- seepage	Slight	- Seepage	- Salt, percs slowly	Very poor	Poor
	Settlemeyer	Yes	0-60	18-35	0.2-0.6	0-2	-	>60	Severe-- floods, wetness	Severe-- floods, wetness	Moderate-- seepage	- Wetness, erodes	Good	Good
	Orizaba	Yes	3-17	30-40	0.2-0.6	2.5-3.5	-	>60	Slight	Severe--wetness	Favorable	-	Fair	Good
NV 65	Vamp	Yes	0-36	12-18	0.6-2.0	3-5	20-40	>60	Severe-- seepage, pan, floods	Severe-- pan, wetness	Moderate-- seepage, pan	- Salt, erodes, pan	Good	Good
	Indian Creek	Yes	5-20	40-70	<0.06	>6.0	14-20	>60	Moderate-- small stones	Slight	- Cemented pan	-	Poor	Poor
	Holbrook	Yes	0-15	0-20	2.0-6.0	>6.0	-	>60	Severe-- seepage	Severe-- seepage	- Slope, seepage	-	Very poor	Very poor
	Leviathan	Yes	9-60	27-35	0.2-0.6	>6.0	-	>60	Slight	Slight	Slight	- Stones	-	-

Table H-2. (continued)

			Estimated soil properties						Limitations and suitability ratings					
State/ site no.	Soil series name	Interpretation sheet present	Clay[a] Depth (in)	Clay[a] %	Permeability (in/hr)[b]	High water table depth (ft)[c]	Cemented pan depth (in)[d]	Bedrock depth (in)[e]	Sewage lagoon	Sanitary landfill (area-type)	Pond reservoir area	Grassed waterways	Wetlands plants	Habitat-wildlife
	Laki	**Yes**	**0-60**	**8-28**	**0.6-2.0**	**2.5-5**	**-**	**>60**	**Moderate--slope, seepage**	**Slight**	**-** **Seepage**	**-** **Excess sodium**	**Very poor**	**Very poor**
OR 20	**Stukel**	**See OR 14**												
OR 15	**Stukel**	**See OR 14**												
	Tulana	**Yes**	**0-23**	**0-28**	**0.6-2.0**	**>5.0**	**-**	**>60**	**Moderate--seepage, excess humus**	**Slight**	**-** **Seepage**	**Slight**	**Good**	**Good**
	Algoma	**Yes**	**0-30**	**0-28**	**.06-0.2**	**1-2.5**	**-**	**>60**	**Severe--floods, seepage, wetness**	**Severe--floods, seepage, wetness**	**-** **Seepage**	**-** **Excess sodium, percs slowly, wetness**	**Good**	**Good**
OR 18	**Stukel**	**See OR 15**												
	Tulana	**See OR 15**												
	Algoma	**See OR 15**												
	Lorella	**Yes**	**10-19**	**35-50**	**.06-0.2**	**>6.0**	**-**	**10-20**	**Severe--depth to rock**	**Slight**	**-** **Depth to rock**	**-** **Rooting depth**	**Poor**	**Poor**

[a] Clay = Percentage given for indicated horizon(s) containing greatest amount of clay.
[b] Permeability = Rate is for least permeable horizon(s).
[c] High Water Table = Depth is for seasonally high, apparent water table (could be a perched water table).
[d] Cemented pan = Dash indicates a pan does not occur above a 60-inch depth.
[e] Bedrock = Depth of observation only to 60 inches.
[f] ID = Idaho.
[g] Severe--Soil has one or more properties that are unfavorable.
[h] No information available.
[i] Good = Soil properties are favorable for the rated use.
[j] MT = Montana.
[k] Moderate--Soil properties are moderately favorable; limitations can ususally be overcome.
[l] Slight--Soil properties are favorable for the rated use.
[m] Fair = Soil properties are generally favorable, although one or more properties make the soils less desirable than those rated "good."
[n] NV = Nevada.
[o] Poor = Soil has one or more unfavorable properties.
[p] NM = New Mexico.
[q] OR = Oregon.

Table H-2. (concluded)

			Estimated soil properties						Limitations and suitability ratings					
			Clay[a]											
State/ site no.	Soil series name	Interpretation sheet present	Depth (in)	%	Permeability (in/hr)[b]	High water table depth (ft)[c]	Cemented pan depth (in)[d]	Bedrock depth (in)[e]	Sewage lagoon	Sanitary landfill (area-type)	Pond reservoir area	Grassed waterways	Wetlands plants	Habitat-wildlife
ID[f] 5	Tica	Yes	5-13	35-45	.06-0.2	>6.0	-	10-20	Severe[g]--depth to rock	Severe--depth to rock	Severe--depth to rock	- Depth to rock	Very poor	Very poor
ID 6	Balaam	No	0-15	0-20	2.0-6.0	-[h]	-	>40						
	Adamson	No	0-18	7-28	0.6-2.0	-	-	>28						
	Molyneux	No	13-50	28-40	0.2-0.6	-	-	>60						
	Brinegar	No	20-33	24-32	0.2-0.6	3->6	-	>60						
ID 7	Balaam	See ID 6												
	Molyneux	See ID 6												
	Gabica	Yes	5-20	24-35	0.2-0.6	>6.0	-	10-20	Severe--depth to rock	Severe--depth to rock	Severe--depth to rock	- Rooting depth	Very poor	Very poor
	Little Wood	No	14-30	22-35	0.6-2.0	-	-	>60						
ID 8	Danskin	No	0-40	0-20	6.0-20	-	-	>40						
ID 9	Brinegar	See ID 6												
	Marshdale	Yes	0-60	18-35	.06-0.6	1.5-2	-	>60	Severe--wetness, floods	Severe--wetness, floods	- Slope	- Wetness	Good[i]	Good
	Roanhide	No	0-24	0.20	2.0-6.0	-	-	>24						
	Riceton	No	10-40	10-18	2.0-6.0	-	-	>60						
ID 10	Brinegar	See ID 8												
	Marshdale	See ID 8												
	Polecreek	No	9-18	30-80	<0.06	-	-	10-20						
	Manard	No	18-26	35-50	<0.06	-	26-28	20-38						
	Houk	No	13-31	35-60	.06-0.2	2.5	-	>60						

Table H-3. Site-specific geologic information

State/site no.	Known geology	Inferred geology
CA[a] 13	Tertiary volcanic flow rocks; minor pyroclastic deposits; major fault in area trending northwest-southeast	Little Hot Spring Valley is aligned on the fault
ID[b] 5	Tertiary basalt flows (some finely crystalline and exposed on upper slopes; some porphyritic and exposed on lower slopes)	
ID 6	Upper Paleozoic deep marine to transitional deposits, thrusted marine detritus; faulting to the south, trending east-west; some Quaternary alluvium--valley fill deposits along Warm Springs Creek	
ID 7	As above; some mixed volcanic lithologies	Floodplain deposits along Big Wood River
ID 8	Mesozoic igneous plutons	Quaternary colluvium, fanglomerate, and talus plus some glacial debris in the uplands valleys; Quaternary basin-filling deposits (downstream)
ID 9	Mesozoic igneous plutons (uplands); Quaternary alluvium (perhaps some lacustrine deposits and colluvium)	
ID 10	Quaternary alluvium, some lacustrine deposits; Tertiary mixed silicic and basaltic volcanic ejecta, flows, and reworked debris; Quaternary plateau and canyon-filling basalt (Snake River Basalt)	Mostly volcanics south of Camas Creek
ID 21	Mesozoic igneous plutons (Idaho batholith--granite, granodiorite, quartz diorite)	Very little alluvium in Salmon River Valley at this location
MT[c] 16	Quaternary glacial lake deposits, mostly silt; near a Precambrian igneous dike or sill (diabase, metagabbro, (may be sandy, quartzitic, or schistose)	Hot Springs Creek appears to have bisected the dike
MT 17	Quaternary alluvium, valley fill (silt, sand, gravel); Precambrian argillaceous rocks as above; near a Precambrian igneous dike or sill	The Clark Fork has bisected the dike
MT 18	L. Cretaceous and Tertiary Boulder batholith (intrusive igneous), mainly quartz monzonite; near Quaternary glacial drift (morainal and outwash deposits, mainly ill-sorted)	
MT 19	Quaternary alluvium, mainly valley fill deposits (silt, sand, and gravel); some Tertiary clastic sedimentary rocks (mostly poorly consolidated gravel, sand, silt, and clay)	Tertiary rocks compose the uplands in northern part of section

Table H-3. (concluded)

State/site no.	Known geology	Inferred geology
NV[d] 15,16	Quaternary alluvial and playa deposits underlain by Tertiary volcanic rocks (silicic tuft, rhyolite, andesite, some sedimentary rocks; sparse basalt); major north-south trending fault directly west	Alluvial fan deposits; about 1 mile east of the fault
NV 17,18,19	As above	Lower piedmont deposits, perhaps playa deposits in eastern half of section
NV 63,64,66 67,68	Tertiary intrusive igneous rocks (granitic and dioritic); some Quaternary alluvium; fault just south, trending north-south	Steamboat Hills is outcrop of intrusive igneous rock; Steamboat Creek may be aligned on fault
NV 65	Quaternary alluvial and playa deposits; fault just north, trending northeast-southwest	Steamboat Creek appears to align on the fault to the north
NV 79,80	Quaternary alluvium and playa deposits underlain by Precambrian and Lower Paleozoic carbonate and transitional assemblages (limestone, dolomite, shale, siltstone, sandstone, quartzite)	Alluvium probably lower piedmont, fan-type deposits
NM[e] 18	Alluvial fan deposits, gravel facies (flood plain and channel deposits along generally dry arroyos and washes; caliche cementation likely); Tertiary volcanics in uplands	
OR[f] 14,17,19	Tertiary waterlaid volcanic rocks (Fluviatile and lacustrine diatomite, volcanic sandstone, laminated siltstone, fine-grained tuff), interbedded in basalt; faulting, trending northwest-southeast	
OR 15	Tertiary and Quaternary basalt and andesite flows; some waterlaid volcanic rocks, as above; Quaternary alluvium; faulting, trending northwest-southeast	Volcanic rocks compose the Klamath Hills, which are separated from the adjacent flood plain and lacustrine sediments of Lower Klamath Lake by a fault
OR 16,21	Tertiary waterlaid volcanic rocks, as in OR 14; Quaternary alluvium (sand, gravel, silt, clay, and pyroclastic debris), near Lake Ewauna; faulting, trending northwest-southeast	
OR 18	Tertiary and Quaternary basalt and andesite flows	
OR 20	Tertiary and Quaternary basalt and andesite flows; Tertiary waterlaid volcanic rocks, as in OR 14; faulting, trending northwest-southeast	

[a] CA = California (Source: Jennings 1977); [b] ID = Idaho (Source: Ross and Forrester 1977, Bond 1978); [c] MT = Montana (Source: Ross et al. 1955); [d] NV = New Mexico (Source: Stewart and Carlson 1977); [e] NM = New Mexico (Source: Hunt 1978); [f] OR = Oregon (Source: Wells and Peck 1961)

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9. Performing Organization Name and Address
CH$_2$M Hill
200 S.W. Market Street
12th Floor
Portland, Oregon 97201

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2625 Redwing Road - Creekside I Building
Fort Collins, Colorado 80526

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15. Supplementary Notes

16. Abstract (Limit: 200 words)

The feasibility of using geothermal effluent water to develop and maintain waterfowl wetlands was evaluated. Idaho, Montana, Nevada, New Mexico, Northern California, Oregon, and Utah were in the study area. Physical and chemical properties of effluent water was described for 206 sites in the seven states. Potentials of the sites for wetlands were evaluated to the extent possible by applying state-of-the-art water quality criteria and considering factors including availability of land for a wetland, land use and typographic suitability for ground water contamination potential, and waterfowl use potential. Sites with the most development potential are in the Beaverhead area, the Camas area of Idaho, and the Nye area of Nevada.

17. Document Analysis a. Descriptors
Water quality
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REGIONAL OFFICE BIOLOGICAL SERVICES TEAMS

Region 1

Team Leader
U.S. Fish and Wildlife Service
Lloyd 500 Building, Suite 1692
500 N.E. Multnomah Street
Portland, Oregon 97232
FTS: 429-6154
COMM: (503) 231-6154

Region 2

Team Leader
U.S. Fish and Wildlife Service
P.O. Box 1306
Albuquerque, New Mexico 87103
FTS: 474-2914
COMM: (505) 766-2914

Region 3

Team Leader
U.S. Fish and Wildlife Service
Federal Building, Fort Snelling
Twin Cities, Minnesota 55111
FTS: 725-3593
COMM: (612) 725-3593

Region 4

Team Leader
U.S. Fish and Wildlife Service
Richard B. Russell Building
75 Spring Street, S.W., Suite 1276
Atlanta, Georgia 30303
FTS: 242-6343
COMM: (404) 881-4781

Region 5

Team Leader
U.S. Fish and Wildlife Service
One Gateway Center, Suite 700
Newton Corner, Massachusetts 02158
FTS: 829-9217
COMM: (617) 965-5100, Ext. 217

Region 6

Team Leader
U.S. Fish and Wildlife Service
P.O. Box 25486
Denver Federal Center
Denver, Colorado 80225
FTS: 234-5586
COMM: (303) 234-5586

Region 7

Team Leader
U.S. Fish and Wildlife Service
1011 E. Tudor Road
Anchorage, Alaska 99501
FTS: 399-0150 ask for
COMM: (907) 276-3800

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